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AN APPRAISAL OF CURRENT AND POTENTIAL REPLACEMENT AGRICULTURAL FEEDS FOR RAINBOW TROUT CULTURE

Thesis submitted for the degree of
Doctor of Philosophy

by

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ABSTRACT

The objective of this thesis is to explore means by which feeding costs incurred in the culture of rainbow trout (Salmo gairdneri) may be stabilised or reduced.

This is achieved by considering novel and traditional feed types and ingredients with regard to their economic potential, comparing performance with that expected using conventional commercially prepared dry compound pellets whose price is linked particularly to fishmeal supplies and which is therefore subject to the upward cost pressures on industrial fisheries worldwide.

Attention is focussed on the scope for developing suitable and more price stable alternatives to fishmeal as a basis for trout diets. Materials are examined individually with regard to price and/or estimated production costs, handling costs and nutritional value to the fish, this latter being determined either on the basis of performance as recorded in the literature or by linear programming analysis of nutrient composition and digestibility. Use of the materials under varying circumstances are discussed and costed and are illustrated by a number of specific examples.

Certain materials appear potentially useful as novel protein substitutes in the manufacture of standard compound pellets, while others would seem to be more economically attractive if used in an alternative fashion, either as a wet diet or as an ingredient in the formulation of a farm-prepared moist diet, for which examples are costed. Projections are made as to the costs and benefits of the various alternatives discussed and recommendations made as to suitable areas of future study.

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PREFACE

The thesis aims to explore means of reducing or stabilising feed and feed related costs in trout farming with reference to the United Kingdom in general and to Scotland in particular. This is achieved by appraisals of existing and potential feedstuff materials, dietary formulations, processing methods and manners of utilisation of feedstuffs.

Chapter 1 serves as an introduction to UK trout culture, describing the biology, feeding habits and natural diet of trout, the growth of trout with regard to food quality and quantity and to environmental factors, the economic structure of the industry, and the major feed types and ingredients used in aquaculture. Price, composition and nutritional quality of feed materials are recorded, and a study is made of the quantities available, regional availability, long term stability of supply and expected price trends.

In order to reduce the number of materials studied to manageable proportions a set of simple selection criteria are drawn up to enable unsuitable subjects to be quickly eliminated. These criteria are discussed in chapter 2 in relation to the economics of trout culture and the manner of evaluation of feedstuffs.

The economic potential of individual feed materials is investigated in succeeding chapters. These materials are grouped into three classes:

Direct materials are taken to include those items, generally high in protein and frequently of animal origin, which may be fed directly to trout, either alone or in combination, with minimal further processing.

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Direct materials are taken to include those items, generally high in protein and frequently of animal origin, which may be fed directly to trout, either alone or in combination, with minimal further processing.

Single cell protein materials cover bacteria, algae and fungi, and include a number which are not strictly unicellular in nature. Distillers' and brewers' residues are discussed here on account of their link with yeasts.

Indirect materials refer to all those nutrient materials which for one reason or another are unsuitable for direct inclusion in trout diets but which may be upgraded biologically by means of the culture of indirect food organisms.

These three classes are to some extent arbitrary and certain of the materials studied could properly be considered under more than one of the categories defined. There are variations however in the manner of appraisal of items within the three classes.

Storage problems common to many of the materials are discussed, and the options of freezing, ensiling and drying are compared, particularly with regard to the use of direct materials. The individual treatments of direct materials and of single cell proteins follow the general format of a historical summary of their use and current practical experience; data on availability, price and nutritional quality; and costed examples of the use of these materials by a hypothetical trout unit, based on the price of the material in question, storage and handling charges, and the conversion ratio expected. These costed examples are compared with estimated costs using conventional dry compound pellets. Factors peculiar to individual items are discussed.

The treatment of indirect materials is similar to that for direct materials but includes an investigation of the additional stage of converting the raw material to the intermediate cultured product, and the estimated cost of production is compared with the nutritional evaluation of the item. A review of the available literature on the culture of live foods is provided.

Materials intended as ingredients in a compound diet are evaluated by linear programming, least cost formulation techniques in combination with a number of commonly used materials. The constraints used in the linear programming model relate to levels of protein, fat and carbohydrate, and to amino acid levels. Fatty acid levels are not included since analyses for these are not generally available for most of the materials studied; because salmonid requirements for these are judged to be too uncertain; and because they are not expected to be limiting in a manner significantly affecting the least cost scenario. Evaluations by commercial feed compounding firms are noted for a small number of the novel materials for comparison purposes. Substitutability between items and evidence of complementary factors are discussed.

Where materials have a history of successful use in trout culture reference is made to the work of other authors as appropriate.

Chapter 6 deals with the manner in which the materials discussed may be used, concentrating on the production of moist pellets suitable for incorporating novel food materials on a farm site basis. Composition, preparation and cost of moist pellets are investigated and are further illustrated by costed examples in an appendix.

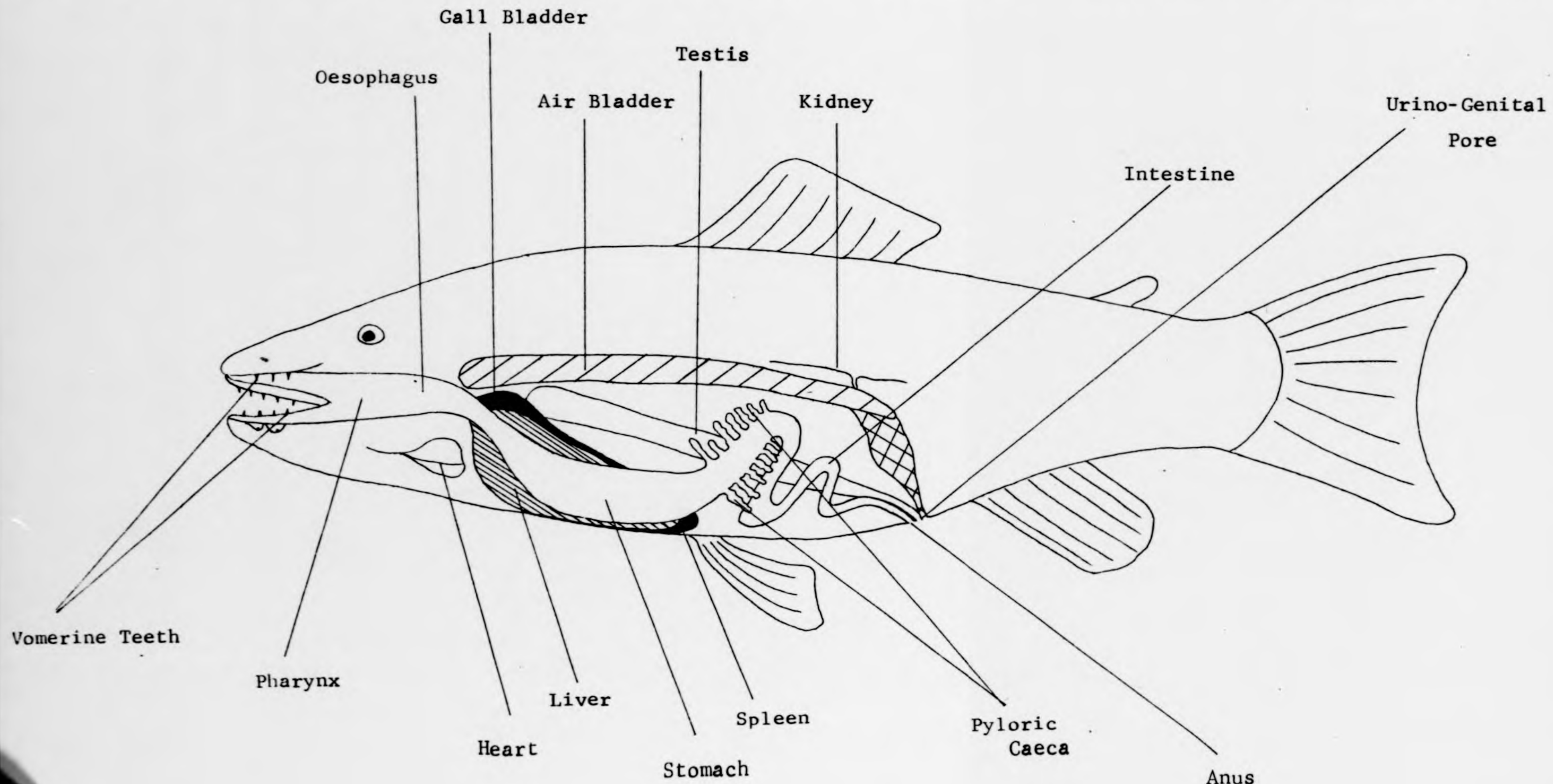
A technological economics assessment of the thesis as a whole is provided in chapter 7, summarising the major factors relating to individual feed materials, their manner of use and their economic potential. Substitutability between items and their stability of supply are discussed, and some projections are made as to future developments and price trends and the extent to which these will affect the main findings of the thesis. Mention is also made of a number of unknown variables which could be of relevance with regard to the use of novel materials.

The work concludes with a brief assessment of the extent to which the stated objectives have been met and the reasons for any shortfalls. A number of recommendations are made relating to both fish farming practice and to further research effort.

CHAPTER 1

Introduction

Diagram 1.1. Digestive System of Trout, Illustrating Relative Size of Stomach and Intestine. (Based on Parker and Haswell, 1928).



1.1 INTRODUCTION TO TROUT CULTURE

Fish culture has been practised in certain parts of the world, notably the Far East and the Middle East, since ancient times. In Europe the Romans are on record as having raised carp in ponds, as at Lago di Paola in Italy, while in mediaeval times carp culture was commonly carried out by the monks, who are widely believed to have been responsible for the introduction of this fish to Britain.

Early systems were not generally intensive, relying on natural spawning and feeding of the stock to a very large extent, and were designed principally to provide a secure supply of protein. The practice died out in much of Europe and the Middle East in subsequent periods, probably as a direct result of improving communications facilitating the delivery of fresh sea fish to inland markets.

In contrast to the antiquity of fish culture in general, salmonid farming appears to be of comparatively recent origin, and has arisen to supply what may be regarded as a luxury market. Trout have been cultured in Europe, including Britain, for rather more than a hundred years, initially for the purpose of restocking lakes and rivers for the sport fishery. The emphasis is now changing, however, and this aspect of the market is now being overshadowed by the production of trout direct for the table. Although Lewis (1979) found that units producing trout exclusively for restocking in Britain outnumbered those producing trout for the table at that time, there is good reason to believe that many of those from the former category were very small units, and that the same pattern will not hold for actual tonnage produced.

Over the period that the emphasis has changed from producing trout for restocking to producing trout for the table, so too has the native brown trout (Salmo trutta) been largely ousted from aquaculture by the North American rainbow trout (Salmo gairdneri). There are several reasons for this. The rainbow trout tends to feed more freely and to grow faster than the brown trout, so that a greater output can be obtained from the same facilities. Furthermore the rainbow trout appears to be more tolerant of high water temperatures, low oxygen concentrations and high stocking densities, all of which are conditions likely to arise on an intensive trout farm. In an industry where the capital cost of installations can be quite high and in which the quantity of good quality water is frequently the major factor limiting production these considerations are of primary importance.

Currently (1980) the United Kingdom produces in the region of four thousand tons or more of trout per annum, by far the greatest part of which is rainbow trout. Government estimates predict that this will rise to between fifteen thousand and twenty thousand tonnes per annum by 1985 (Jones, P, 1980) bringing us more into line with production levels achieved by other trout producing countries such as France, Germany, Denmark and Italy ("The Scotsman", 1979). Lewis (1979) showed that at that time Britain ranked a poor sixth in annual rainbow trout production, producing less than 20% of the output of countries such as Italy, Denmark and France (see Table 1.2). Such an estimate may be regarded as rather optimistic in some quarters, assuming as it does that either a substantial export market can be developed or alternatively that a marked rise in home demand will occur, a trend which at present shows little sign of materialising despite the increasing competitiveness of farmed trout compared with wild caught fish such as cod and haddock.

Current market research indicates that trout consumption in the United Kingdom stands at approximately two ounces per year (Lewis, 1979). This figure appears to refer to purchased trout only, and does not include wild caught trout from natural fisheries (as opposed to put and take fisheries) which in this instance may supply a very considerable part of the total consumption.

While it is likely that a limited market will remain for brown trout reared solely for restocking purposes, trout culture in the United Kingdom in the near future will probably continue to be dominated by the rainbow trout unless new hybrid strains showing significant advantages of growth and/or survival are successfully introduced.

In addition to brown and rainbow trout, at least two other salmonids are also cultured in Britain. Brook trout (or brook char) (Salvelinus fontinalis), although originally introduced in the last century, have recently achieved some popularity for stocking sport fisheries; while the Atlantic salmon (Salmo salar) is now being cultured along parts of the British coast, principally on the West coast of Scotland. The latter species in particular appears to offer excellent prospects for growth (Table 1.1).

Certain other species are also being studied with a view to possible introduction to and culture in the United Kingdom, notably the Pacific salmons (Oncorhynchus SP), while huchen (Hucho hucho) and artic char (Salvelinus alpinus) remain possibilities for the future.

TABLE 1.1 CURRENT UK SALMONID PRODUCTION AND GOVERNMENT ESTIMATES FOR PRODUCTION IN 1985 (FROM "THE SCOTSMAN", 18/6/1979).

TROUT PRODUCTION:	
CURRENT	4,000 Tonnes per annum
1985 (Estimated)	15,000-20,000 Tonnes per annum
SALMON PRODUCTION:	
CURRENT	500 Tonnes per annum
1985 (Estimated)	5,000 Tonnes per annum
(Wild Caught; Current)	1,500 Tonnes per annum

TABLE 1.2 EUROPEAN PRODUCTION OF RAINBOW TROUT IN 1976 (AFTER M.R.LEWIS, 1979)

COUNTRY	TONNES PER ANNUM (1976)
ITALY	17,000
DENMARK	15,000
FRANCE	15,000
GERMANY	10,000
SPAIN	6,000
GREAT BRITAIN	2,500
NORWAY	1,800
AUSTRIA	1,000
EIRE	400
BELGIUM	400
SWITZERLAND	400
N. IRELAND	200

1.2 NATURAL FOODS AND FEEDING OF TROUT

1.2.1 In those areas where both brown trout and rainbow trout occur together little difference is observed in their feeding, and no distinction is therefore drawn between the two species as regards their "natural" diet in Britain. Both species are representative of most salmonids.

The trout is considered to be a general carnivore, taking animal foods of a wide size range, from daphnids and midges to other fish and small mammals (Table 1.3.) according to the environment, season and abundance of particular food items. They exhibit few anatomical specialisations for capturing and digesting their prey, teeth are simple and small, salmonids generally swallowing their food whole. Digestion takes place primarily in the stomach (Huet, 1972) and the intestine is relatively short (see diagram 1.1). Trout are not thought to eat vegetable matter deliberately in nature, and such fragments of vegetation as have occasionally been found in trout stomachs are believed to have been ingested by accident. There are exceptions to this, however, and trout are recorded as containing semi-digested water plants and large quantities of the round alga Nostoc (Frost and Brown, 1967.).

1.2.1.1 The feeding habits of trout change to a degree as they mature. As young fry trout appear to feed mainly on drifting food organisms, (the "living drift" of some writers), themselves remaining poised in the current (Myers, 1946) and being apt to starve if such drifting food is not available.

Adult trout may also be observed feeding in this manner, especially in running water, but after they are two or three months old they become much more active predators, searching out their food to a greater extent. (Sawyer, 1944). The eyes appear to play the major role in the trout's search for food, although it is possible that the highly receptive lateral line may also be important in the location of prey by responding to the prey's movements. This may be particularly true in the case of night feeding trout.

Trout feed at all levels in the water, the emphasis frequently varying with time of day, season, water temperature, locality and the characteristics of individual trout. In rivers and lakes with abundant natural food there is a tendency for trout to be more bottom and midwater feeders than trout in oligotrophic environments where organisms of terrestial origin may provide a very substantial part of the diet. (Frost and Brown, 1967).

1.2.1.2 In the first year after hatching the trout's diet is made up largely of midge larvae, cladocerans, gammarids, mayfly nymphs, caddis larvae and some terrestial invertebrates. This diet is subsequently expanded to include larger food organisms such as snails, beetles and sometimes small fish. The food eaten by trout remains much the same throughout the adult lifespan of the fish, with larger trout able to consume a slightly greater range of larger organisms and/or organisms with hard external protection. The stomach of the trout is able to extend posteriorly to accommodate relatively large prey. (Smith, 1980). In addition there would appear to be some evidence that older trout consume more surface food of aquatic origin, such as the adult stages of mayflies, caddisflies and blackflies, than young trout. (Frost and Brown, 1967). Larger trout are also sometimes inclined to piscivorous habits, especially in oligotrophic environments. Fish eaten by trout include virtually any small enough to be swallowed, such as other trout and also spiny fish such as sticklebacks and perch. Shoaling fishes - minnows, sticklebacks and roach fry - would seem to be preferred. Other vertebrates, such as frogs, newts, voles and mice, are sometimes eaten by trout, but with the possible exception of frog tadpoles in some still waters these rarely form a significant part of the diet.

1.2.1.3 There has not been a great deal of detailed scientific work on the attributes by which a trout recognises a particular item as food. Movement appears to be of major importance although it is not at present clear whether this is because only moving material is initially regarded as food or because the movement attracts the attention of the trout. Quite possibly it is a combination of these factors. Stationary objects are also frequently eaten by trout, although this does seem to be more or less limited to those items which resemble food previously consumed. An insect floating on the surface of the water will be consumed even though it may be dead since it possesses the visual characteristics of food which has been eaten previously which may have been moving. It should of course also be noted that even with a floating spent fly slight movements of the legs and wings may be apparent as a result of water and wind movements.

Just as trout are prepared to accept stationary items with the visual characteristics of food, so also will they sometimes accept items which lack the visual characteristics of food but nonetheless do possess movement, and will frequently seize bits of gravel falling through the water although non-edible items such as these are usually ejected again almost immediately.

1.2.1.4 A great number of organisms have been recorded from the stomachs of trout, such as those listed in Table 1.3. The quantity of each food item consumed is believed to depend primarily on the abundance of that particular food item and on its accessibility to the trout. The extent to which an item is eaten by trout relative to the abundance of that item in the fauna is given as the forage ratio. This is defined as being the percentage of the species found in the trout's stomach divided by the percentage of that same species found in the fauna. The forage ratio tends to be high for those organisms that are conspicuous, active, devoid of protection or living in exposed situations, and tends to be low for those that are concealed, sedentary or protected by living among weeds or under stone. Protection mechanisms such as hard external coverings (shells, spines, etc) are not as effective as against many other predators, and caddis larvae, snails and sticklebacks are all readily eaten by trout of sufficient size. The habitat of a food organism is of more importance in determining the forage ratio, and those animals which spend their whole lives under stones or burrowing in the bottom sediment are rarely eaten unless dislodged by floods or other activities. Similarly those organisms which spend their larval stages in protected habitats but ascend to the surface at maturity are most commonly eaten during that relatively short period when they are exposed. This can be assumed to be almost certainly due to the relative ease of locating the organism, since many of these stages can be shown to be almost equally acceptable to the trout if presented in a similar fashion.

Other factors which affect the extent to which various organisms are eaten by trout include the speed of movement of the prey and the degree of camouflage. Trout may be observed rejecting edible items which they have seized, suggesting also some degree of selectivity based on the palatability of the item.

Abundance of an organism should not in itself affect the forage ratio, since the abundance is itself the denominator of the ratio by definition. In fact this is not necessarily the case, and great abundance of a particular item, especially when transitory, may lead to a high forage ratio. This is frequently the case when a "hatch" occurs of a particular fly, during which time trout will evidently select that fly virtually to the exclusion of all else, even though other items may themselves by quite abundant at the time. The reason for this behaviour is not clear, although the effect is advantageous to the trout population as a whole in that it enables a transitory food supply to be fully utilised in preference to more permanently accessible food items such as the normal bottom and midwater fauna. There has been some work done on this aspect of trout behaviour, notably that by Allen (1941) who suggested that selection was most apparent when trout were feeding heavily and food was abundant, as might perhaps be expected. This is of some relevance in attempts to feed trout on more than 1 item, i.e. pellets + complementary feeds, etc, since some items might be under-utilised or fish might exhibit individual preferences for particular items, possibly leading to an unbalanced diet.

1.2.1.5 The diet of trout shows both diurnal and seasonal fluctuations, as demonstrated by a number of studies. (Swift, 1961; Frost and Brown, 1967). Seasonal fluctuations are almost certainly due in part to the changing abundance of the various food items and complementary to changes in the abundance of the various items may be changes in their habits, some items becoming less accessible in winter due to burrowing deeper or lying dormant while other items become more accessible as the aquatic vegetation which previously concealed them dies back. In addition to this, there does appear to be some actual preference shown for particular items at particular times of the year, and it may be that certain organisms are only eaten at all when other food items are in short supply.

1.2.2 It should be noted that our records of the natural food of trout are rather incomplete at the present time, much of the information coming from the examination of rod caught fish which could clearly indicate a strong bias in the sample towards the type of bait being used. Those samples taken by other methods such as netting are probably better, but the stomach contents of the fish may still not be truly representative since those items with indigestible hard parts, such as snails, tend to remain in evidence rather longer than soft bodied items such as earthworms.

1.3 FOODS AND FEEDING OF FARMED TROUT

1.3.1 While the food of farmed trout may be quite different to that of wild stock, nonetheless the feeding habits of the fish remain essentially the same and are of some relevance in many aspects of trout culture.

The natural diet of trout is high in protein, and this is

TABLE 1.3 COMMON NATURAL FOODS OF TROUT IN THE UK (FROST AND BROWN, 1967; RUSHTON, 1931)

Mayfly	Adults, Nymphs
Stonefly	Adults, Nymphs
Caddis Fly	Adults, Pupae, Larvae
Diptera	Adults
Midge	Adults, Pupae, Larvae
Dragonfly	Adults, Nymphs
Blackfly	Larvae
Alderfly	Adults, Larvae
Chaoborus (Phantom Larva)	Larvae
Cladocera	All Stages
Gammarus	All Stages
Asellus	All Stages
Snails	All Stages
Pea Mussels	Juveniles
Corixa	All Stages
Newts	All Stages
Frogs	Tadpoles, Juveniles
Fish	Small Species, Fry, Juveniles

mirrored in the high protein content of commercially prepared trout feeds (Appendix A)(generally between 35% and 55%). In the natural diet the protein is supplied almost exclusively in the form of animal protein, whereas in the compound pelleted diets it has been found possible to replace at least part of this with cheaper vegetable protein, more of which is said in the section on nutritional requirements of trout. In the United Kingdom virtually all intensively reared trout are now fed on pelleted "complete" diets, although in the past many other materials have also been used, while in both America and Continental Europe offals, industrial fish species and some live foods are widely used, the latter especially for young fry.

1.3.1.1 The stage at which fry first begin to feed after absorbing the yolk sac is of crucial importance to the fish farmer, and losses can be heavy at this time if conditions are not entirely suitable. One of the major problems is in getting the fry to feed, and if failure occurs in this many of the fry will simply starve to death. This difficulty stems from the habit of wild fry in feeding on the drift for the first few weeks of life, taking food brought to them on the current rather than searching it out. Huet (1972)states that brown trout are more difficult than rainbow trout in this respect.

When compound feeds are used to rear fry, they are in the form of a crumble of particle size in the region of 0.2mm diameter. Initially, fry appear to be unwilling to pick food off the bottom but will take it as it falls through the water and is borne along by the current. For this reason it is desirable that the rearing troughs should not be too shallow, allowing adequate time for the food to be eaten before it reaches the bottom, and the feed should preferably be of the slow sinking variety. Even so it is to be expected that some of the fry will fail to eat and will die of starvation.

Rainbow trout appear to feed more readily than many other salmonids at this stage and most will accept the crumble feed from the start. Brown trout and Atlantic salmon fry on the other hand are reported to be more temperamental at this stage and may refuse an artificial diet. For this reason, some producers, though probably not many, use other feeds initially such as finely ground liver, or better still, small live foods (daphnids, etc). The cost of feed used at this stage is of relatively minor importance due to the very small amounts involved, and the advantagesto be obtained from raising healthy fast growing fry are usually considered more than adequate compensation for the higher cost of feeds deemed to be superior (Section 2.1). Flaked feeds, as used for aquarium fish, have achieved very little usage in commercial fish culture. However, Webber and Huguenin (1979) suggest that flakes could find a usage in feeding certain juvenile fishes.

1.3.1.2 Rainbow trout tend to become accustomed to a particular type of food and a short weaning period may be necessary if a new feed differs substantially in visual aspects from the old. This is the case when dried crumbles or pellets are first fed to fry fed previously only on live foods. Trout, however, appear to be capable of "learning" by example, and this naturally has more chance of occurring where large number of trout are held together than among the very small numbers of trout frequently used for laboratory studies. Huet (1972) goes so far as to suggest this "copying" characteristic as a good reason for stocking ponds heavily.

1.3.1.3 Fry are usually raised in concrete troughs or fry rearing tanks until they reach a size of around 4" (at which stage they are called fingerlings). In extensive fish farming practices, the fish are then placed in large ponds at quite low stocking densities and are left to feed on the natural production of the water, which may be encouraged in some cases by the addition of fertiliser. Extensive methods of fish farming are not widely used in Britain for trout, except sometimes where fish are required for stocking a sport fishery. Where trout are destined for the table market, intensive production is the usual practice, in which fish are stocked at very high densities in quite small ponds or tanks but with a good flow of water. Due to the very high densities natural food production is insignificant and the trout rely virtually entirely on artificial feeding. A third system of fish farming is intermediate between the two extremes and is termed semi-intensive. Here trout are stocked in ponds with significant natural production but with supplementary feeding also. This method is not used much in Britain for trout production, although it is quite popular with those raising coarse fish for sport fisheries.

1.3.1.4 In intensive systems, the fry are transferred from the rearing facilities to larger containers which take a wide variety of forms - earth ponds, concrete ponds, fibreglass tanks, silos, raceways and floating net cages. They are then fed regularly and grown on to market size (or retained as broodstock).

Where pellets are fed, these may be broadly categorised into three types - floating, slow sinking, and fast sinking - each having certain advantages and disadvantages depending on the method of culture in use. Feeding methods include hand feeding, automatic feeding and self feeding.

Hand feeding is time consuming and labour intensive, and may also result in longer than optimum intervals between feeds. However, provided the fish may be hand fed sufficiently regularly, hand feeding has been found to provide better feed conversion efficiency and faster growth than demand feeding (Seymour, 1977; Andrew and Page, 1975). Many fish farmers adopt a compromise stand and feed the fish by hand at least once a day to keep an eye on the response and health of the stock but rely on other feeding methods to supply the bulk of the feed. Floating pellets are popular for use in hand feeding since this enables the feeder to see how much is actually being eaten. In addition feed wastage through pellets sinking into the bottom sediment is avoided. On the other hand, in a fast current (raceway, etc) losses may occur through the pellets floating out of the ponds if the fish are not feeding vigorously.

Automatic feeders supply a fixed amount of feed to the pond at predetermined intervals of time. A great many systems for achieving this have been designed by individual farmers, although those produced industrially mostly work on the principle of using compressed air to blow out the feed over the pond, or else use a rotating disc which scatters the food by centrifugal action. Two major types of pneumatically operated feeders occur; a feeding carriage which is borne on rails around the ponds and is connected to an air blower, feeding each of the ponds in turn; and an individual feed container placed at the end of each pond, and all being connected to a common air blower. Both types are operated by an adjustable time switch. (Diagrams 1.2 - 1.7).

Automatic feeders find their greatest use for fry rearing tanks, where the fish require to be fed at rather more frequent intervals than larger trout. Some are also used however to feed bigger fish in ponds, and their major advantage is that they permit feeding at short intervals without excessive use of labour, resulting in good feed conversion efficiencies. The main disadvantage is that automatic feeders are set to discharge a predetermined quantity of feed regardless of the appetite of the trout, and wastage can then occur from much of the food remaining uneaten when the fish are not feeding as vigorously as usual for any reason.

Automatic feeders may also find a use on floating net cages, where access for hand feeding is less easy than in shore based installations. They may be used with any reasonably hard pelleted feed, although it should be noted that for fry tanks and floating cages fast sinking pellets are not totally satisfactory since it is not desirable that food should reach the bottom uneaten. Conversely, for silos fast sinking pellets may well be essential to permit food to reach fish in the lower layers.

Self feeders or demand feeders are an interesting idea in trout feeding equipment and have been used with some success. The principle of these feeders is that trout themselves operate the feed release mechanism, such that feed is discharged to the pool as and when the trout require it. This can result in good feed conversion efficiencies and very little wastage. There are several designs in use, the best known of which consists of a rod suspended at one end through a hole at the bottom of a hopper which releases feed when the trigger is operated by the movements of the fish. (Diagram 1.8). The amount of feed released corresponds to the demand (frequency of triggering) of the fish and can be controlled to some extent to approximate to the manufacturer's recommended feeding levels. (P.J. Landless, 1976). Demand feeding is a very satisfactory system for trout in ponds once they have attained sufficient weight to operate the trigger (although scaled down versions may be available for smaller fish). However the feeders currently produced suffer from one or two design faults resulting in periods when the fish are not being fed until the defect is noticed.

Automatic and demand feeders are not generally suitable for wet feeds such as minced fish. Many of the potential trout feeds to be discussed in this thesis would therefore not be suitable for use in such systems without substantial design changes in the equipment, although a number of experimental designs have been claimed to operate satisfactorily. (Webber and Huguenin, 1979; MacFarlane, 1976; Pozar, 1968). Commercially available models of feeding equipment used in Europe are reviewed by Berka (1973) and a number of both commercial and experimental designs are illustrated in Figs. 1.2 - 1.8.

A complete time-operated automatic feeding system capable of delivering up to 30 tons of pelleted feed per annum (if refilled daily) may be obtained for as little as £200, which, depreciated over 10 years, works out at £0.67 per ton of feed delivered - around 0.2% of the feed cost. In practise, a time-operated automatic feeding system will vary greatly in price, depending on the lay-out of the farm and the number of ponds, each pond requiring a feeder rather than the number of feeders being determined by specific quantities of trout. On the other hand, several feeders should be able to make use of common time switches/control units, etc. Due to the relatively small cost of feeding systems the cost of automatic feeders is hereafter considered to be negligible where the cost of pellets fed automatically is being compared with hand fed wet feeds.

Figs 1.2 - 1.8. Simple Automatic Feeder Designs.

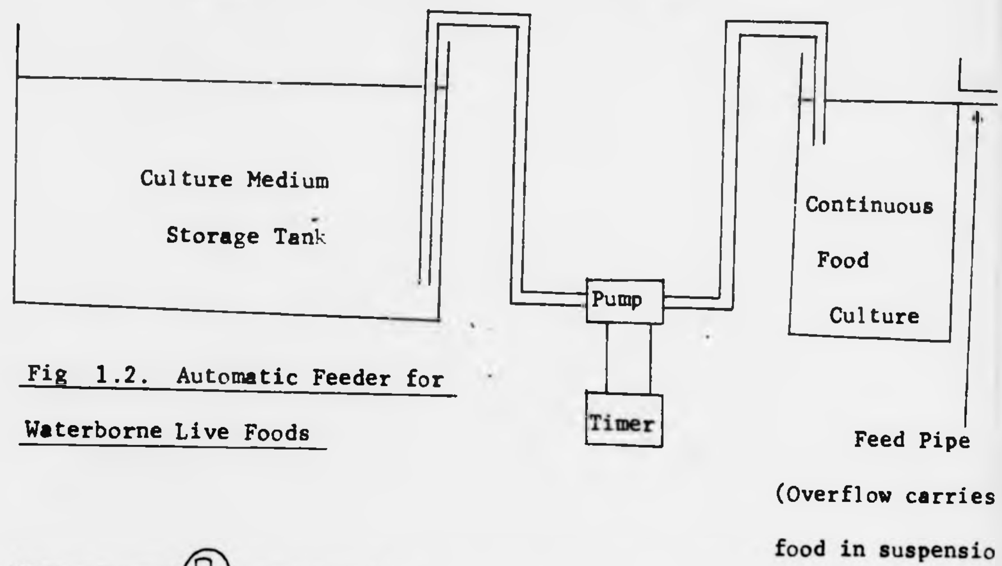


Fig 1.2. Automatic Feeder for Waterborne Live Foods

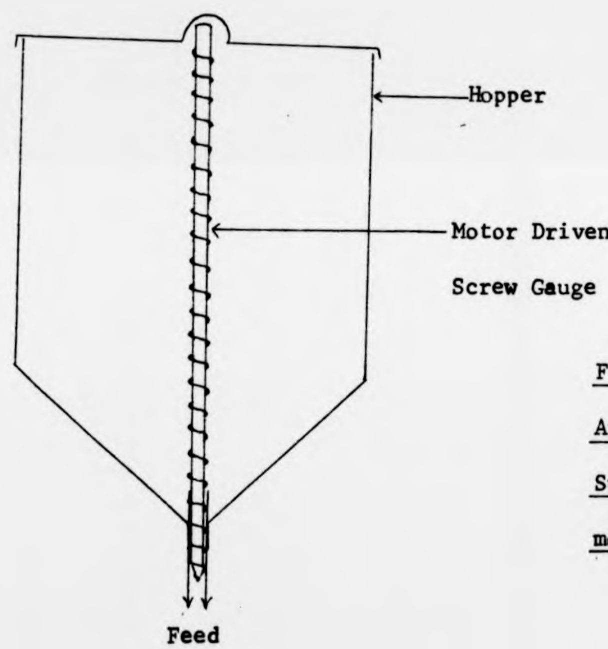


Fig 1.3. Type 1 Screw Augur Automatic Feeder Suitable for mixed wet and moist feeds

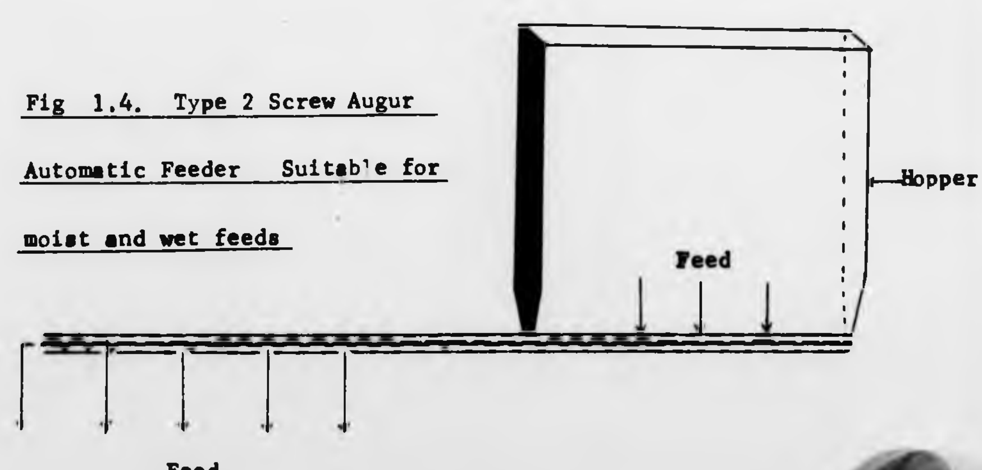


Fig 1.4. Type 2 Screw Augur Automatic Feeder Suitable for moist and wet feeds

Simple Automatic Feeder Designs; Quantities of food dispensed may be controlled either by adjusting the aperture or (except in the case of demand feeders) by adjusting the time switch

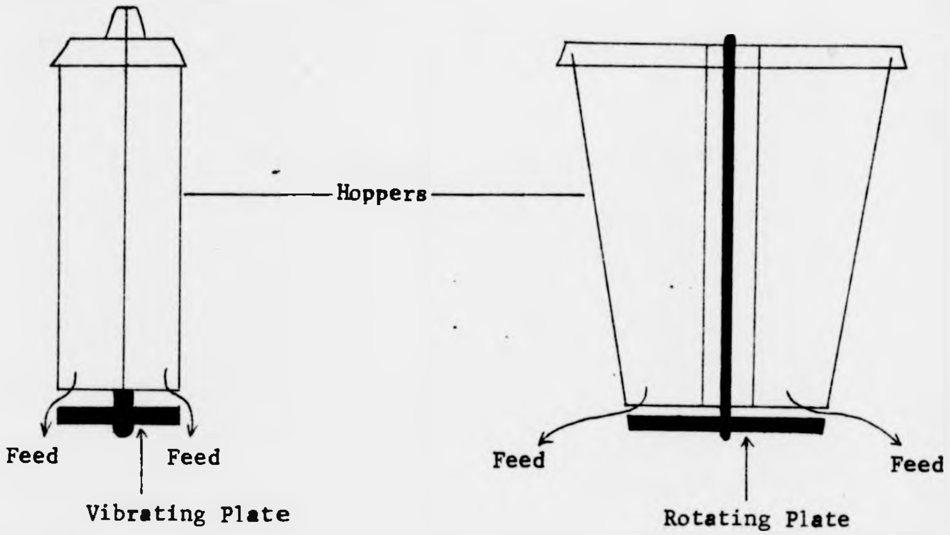


Fig 1.5. Vibrating Plate Design

Fig 1.6. Rotating Plate Design (More suitable for moist pellets on account of large aperture and reduced compression)

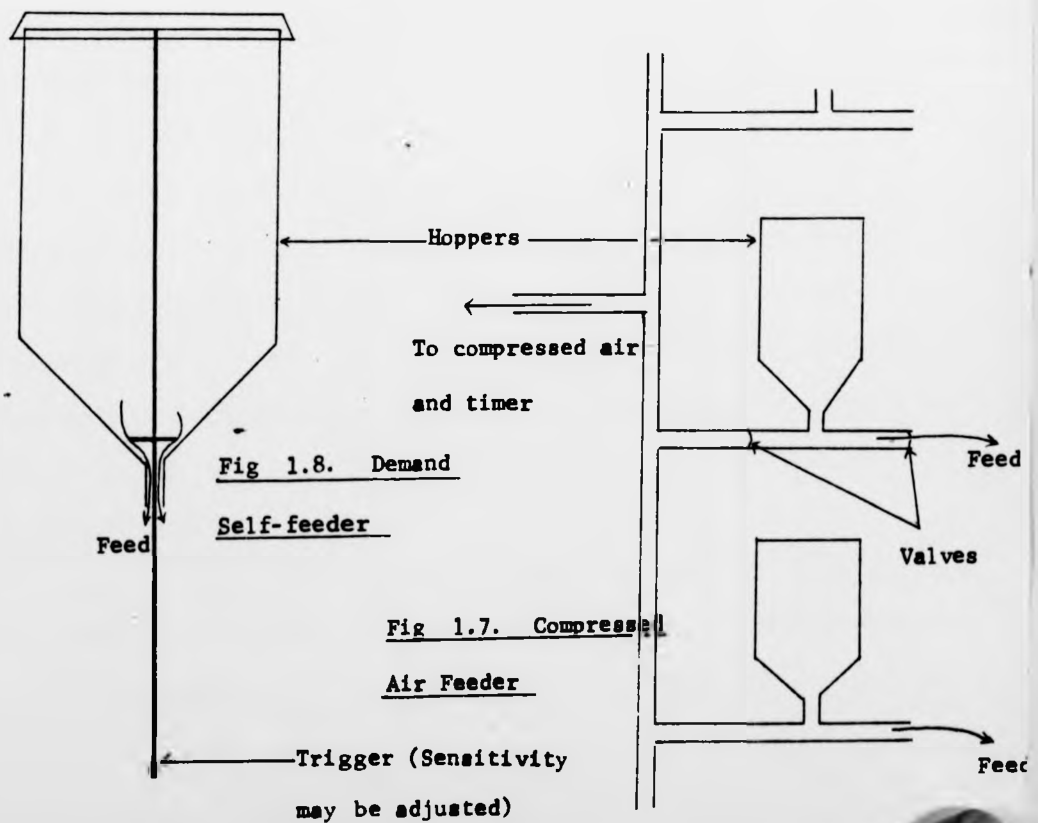


Fig 1.8. Demand Self-feeder

Fig 1.7. Compressed Air Feeder

1.4 GROWTH AND FOOD REQUIREMENTS OF TROUT

1.4.1 The diet must supply the trout with energy, protein, minerals and vitamins in a form that can be used. In spite of a number of recent modifications, work done by Halver and co-workers or by Philips in the late 1960's probably provides the most widely accepted standard of trout feed requirements.

The requirement for specific nutrients is central to the evaluation of feedstuff ingredients and is discussed fully in Chapter 2 where the methodology used in this work is described. It is considered appropriate to consider here therefore the general aspects of feed requirements only.

Energy is the first essential element in any diet, powering the metabolic processes of the body. The main sources of this in natural diets are fats and oils, although carbohydrates may also supply a significant part in commercially prepared diets. Proteins can be broken down as an energy source if required by the activity of the trout or by an imbalance in the diet.

While the role of carbohydrates appears to be virtually confined to that of an energy source, many amino acids and some fatty acids are regarded as essential in their own right. The specific requirements for these are recorded fully in the appropriate section in Chapter 2. There is however also a general requirement for protein as a raw material for growth, being used in tissue generation and re-generation. In the case of wild trout, the diet may at times be very high in protein, such that there is insufficient energy supplied by the fats and carbohydrates with the result that part of the protein may itself have to be used as an energy source to permit full metabolisation. For farmed trout to utilise protein in this fashion would be economically inefficient, and the diets are therefore balanced with the intention that the entire metabolisable energy requirements are met by the cheaper fats and carbohydrates. Most commercially prepared compounds contain in the region of 40% protein, varying to some extent with protein quality and with the state of development of the fish.

Fish are able to obtain minerals and essential trace elements both from the diet and also in some cases from the water in which they live. The extent to which they are capable of extracting trace elements from the environment is however poorly known. Specific requirements for a number of trace elements have been demonstrated and are recorded in Chapter 2. A number of vitamins are also considered essential to the proper development of trout, although considerable further work is required to investigate relationships between vitamin requirements and external factors. Our current knowledge of vitamin requirements is also summarised in the appropriate section in Chapter 2.

1.4.2 The desired effect of any food for farmed fish is that it should produce rapid growth while maintaining the fish in good marketable condition. In the study of wild trout populations growth is taken to mean an increase in length rather than an increase in weight on account of the latter's tendency to show marked temporal fluctuations. This is however not very satisfactory as a measure for growth of trout in fish farms, since individual measurements are time consuming and would in any case need to be converted to weight estimates in order to determine the feed conversion efficiency.

To the fish farmer, growth is therefore generally taken to mean an increase in weight, since this is the criterion by which fish are sold. Nonetheless the fish should be presentable, and there are problems in marketing excessively fat trout, or indeed in marketing any trout that differs appreciably from the fish the consumer is used to.

1.4.2.1. The relationship between length and weight is sometimes used as a measure of the condition of a fish, the condition factor K being defined as:

$$K = \frac{1000 \text{ X Weight in lbs.}}{0.427 \text{ X} (\text{Length in inches})^3} = \frac{100 \text{ X Weight in g.}}{(\text{Length in cms.})^3}$$

(Frost and Brown, 1967).

For a wild trout in good condition, the K value should approximate to 1. However, there is a great deal of variation between species, and for a rainbow trout raised for the table it would be quite acceptable for the K value to exceed unity.

The length/weight relationship is but one aspect of condition, and spawning trout are generally regarded as being out of condition (especially the males) as soon as the gonads approach ripeness even though the K value may still approximate to unity. The ripening of the gonads affects the quality and flavour of the fish by using up much of the reserve food stored in the body of the fish. It also greatly slows growth by diverting nutrients which could otherwise be used to build more body tissue. For these reasons it is desirable to avoid sexual maturity in the fish

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1.4.2.2 For scientific studies, the best measure of growth is probably the specific growth rate, also known as the geometric, incremental or instantaneous growth rate. This is defined as follows:

$$Y_T = Y_t.e^{g(T-t)}$$

Where Y_T is the final size (at time T)

Y_t is the initial size (at time t)

T t both are expressed as units of time

e is the base of natural logarithms

and g is the specific growth rate.

(Frost and Brown, 1967).

This is satisfactory for experimental observations on wild trout and also for laboratory work on cultured trout (in the former case age and some estimate of growth may be obtained from interpreting the annuli on scales and otoliths). It is not well suited to recording growth on fish farms, however, where the aggregate weight of all the fish in a pond is considered an adequate and more easily obtained measure of fish growth.

1.4.3 Trout vary enormously in their growth rate whichever measure is used, this variation arising from a number of interrelated genetic and environmental factors. Rainbow trout are generally considered to be faster growing than brown trout, and also tend to be shorter lived. Superimposed on this intraspecific variation, however, is a large element of interspecific variation, and a great deal of breeding research has been directed at producing faster growing strains of trout, either by selection or by means of hybridisation. These fish breeding programmes have been quite successful, although they have been in operation for only a short period when compared with breeding programmes aimed at other domesticated animals such as pigs and poultry, such that it is now possible, if desired, to produce 20 lb plus rainbow trout at three years of age (the Avington strain of trout being particularly well known for the high growth rates achieved). The majority of fish produced on UK trout farms, however, are portion-sized rainbow trout of between 5 and 8 ozs. (Lewis, 1979). This weight is generally reached at some stage during the second summer, depending on the climate, strain and method of husbandry.

As well as good growth rates, the operator producing trout for the table market is interested in selection for a number of other factors, including good feed conversion, flavour and appearance, and low mortality and compatibility with high stocking densities. It should be borne in mind that many of the recently developed fast growing strains of trout are not necessarily good converters of feed and will only grow faster than other strains if the prevailing conditions (food supply, temperature, etc) permit them to achieve their full potential. This has been a source of disappointment in a number of cases where a fast growing strain has been stocked or introduced to a new environment and has given very mediocre results. Conversely, there are also instances where trout introduced to a new environment have shown spectacularly high growth rates. (This has been frequently found to be the case where fish are introduced to environments well separated from the natural geographical range of the fish, e.g. as with brown trout introduced to Kenya and New Zealand. There are several possible reasons for this, one of which is that diseases of the species which depress growth but do not cause a high mortality may not be established in the new environment).

Environmental and seasonal factors affecting growth are closely interrelated, such that it is difficult to separate the effects of one from the other. Some workers (Someren, 1950; Frost and Brown, 1967) have suggested that trout may have an internal biological clock governing their activity irrespective of environmental factors, and if this were shown to be the case this could be considered as a truly seasonal effect. In the majority of instances, however, levels of activity associated with the season may be traced to a distinct physical factor of the environment such as day length or water temperature.

Pentelow (1939) found that trout growth was approximately proportional to food intake, and it is highly likely that variations in growth rate associated with water chemistry and other environmental factors may frequently be dependent primarily on food availability. Many food items of wild trout - molluscs and crustaceans in particular - require moderately hard water in order to form their external skeletons, and where water is soft food is often restricted. From studies on wild trout populations in Britain there is a clear correlation between trout growth and water hardness, but variations in water temperature, degree of temperature fluctuation, flow speed, altitude and day length all serve to complicate the issue such that it is difficult to isolate particular causative factors. Laboratory studies under controlled conditions may be of greater value in this respect.

A regular annual growth rate cycle has been demonstrated in both wild and hatchery raised trout, high growth rates occurring in the spring and autumn. Similar variations in growth rate have also been found in experimental laboratory trials in which food is not limiting, and temperature and day length are therefore considered to be the two most likely causes of "seasonal" variations.

Swift (1955, 1961) states that temperature is the main factor involved and that the maximum growth rate of brown trout is achieved at approximately 12^{o}C. This contradicts to some extent the results of Brown (1946) who reported that brown trout grew fastest between 7^{o}C and 9^{o}C and between 18^{o}C and 19^{o}C, although it is noted that Brown's samples were small and that standard deviations were large. It should also be borne in mind that the temperature at which Swift and Brown kept their trout prior to the experiments are not recorded, and if these temperatures differed this would have resulted in different acclimatisations.

Being poikilothermic, the major reason for decreasing growth rates at lower temperatures would appear to be the progressive loss of the trout's appetite. Below about 4^{o}C trout have been observed to virtually cease feeding, and many trout farmers do not feed their stock at low temperatures in winter. At higher temperatures the cause of depressed growth rates is not so clear.

Pentelow (1939) found that food consumption of brown trout fell above 15^{o}C, but Fry (1957) suggests that it may be the respiratory system rather than food consumption that restricts growth in fish at high temperatures. As the oxygen content of water falls with increasing temperature, the ventilation rate rises faster than the respiration rate. Therefore the utilisation of oxygen, falling with increasing ventilation rates, falls also with increasing temperature, greatly increasing the cost, in energy terms, of respiration.

1.4.4 Rainbow trout are regarded as having higher optimum temperature requirements than brown trout, temperatures of between 14^{o}C and 16^{o}C being on record as producing the fastest growth rates. Other workers have suggested that rainbow trout feed best at 16^{o}-18^{o}C, and will continue feeding at 24^{o}C. (Lavrovsky, V. V, 1968). This does not necessarily contradict the report that they may grow between 14^{o}C and 16^{o}C. Rainbow trout are also reported to have higher tolerance limits. The upper tolerance limit for brown trout (measured as the highest temperature at which half the trout of a sample survive for the stated period of time) has been found to be between 22.5^{o}C and 25.3^{o}C (Frost and Brown, 1979) for periods up to seven days, depending on the acclimatisation temperature. For culture purposes, however, a mortality of 50% in seven days is unrealistic and the temperature should not exceed 20^{o}C for more than very short periods if mortality is to be kept within acceptable levels. Rainbow trout on the other hand can be raised satisfactorily in temperatures of up to 23^{o}C as long as oxygen levels are maintained by aeration where high stocking densities occur.

1.4.5 In all agricultural practices it is desirable to feed the stock at a level which promotes good growth but not to the extent that large quantities of the feedstuff are wasted by remaining uneaten or being inefficiently utilised. For this reason manufacturers of pelleted trout diets frequently supply charts stating the recommended feeding levels for their product at varying temperatures (Appendix B).

Trout will grow only whenthe intake of food exceeds the maintenance requirements needed to sustain bodily processes such as respiration, excretion and replacement of damaged tissues. The maintenance requirement is defined as the quantity of food required to maintain a fish in its current condition with no loss or gain in weight, and is measured as a weight of food intake per unit weight of the fish. Any excess food over the maintenance requirement can be used for growth of bodily tissues and/or reproductive organs, the latter being purposefully minimised in the culture situation (except in the case of brood stock). The relationship between food intake and growth may thus be summarised, in a much simplified form, by the following equation:

$$I = M + G$$

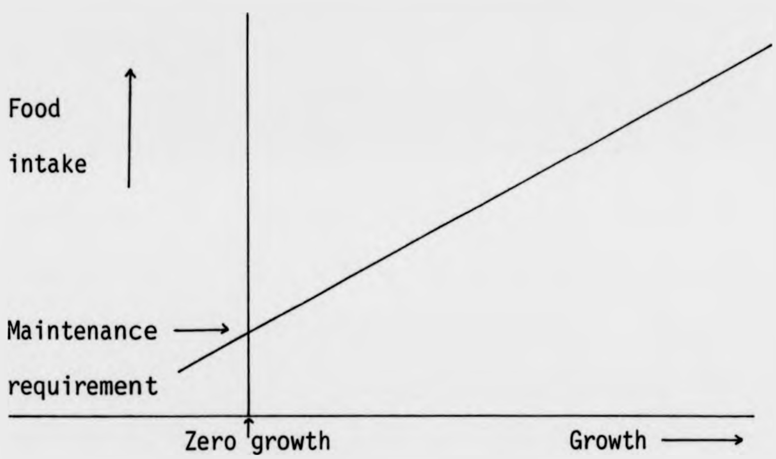
where I = Total food intake

M = Maintenance requirement

and G = Part of food intake used for growth.

1.4.5.1 The maintenance requirement is generally regarded as remaining constant for a particular trout of known weight at a given temperature, remaining unchanged by variations in food intake. (In fact this is not entirely the case, since the food intake can affect the activity of the trout, thus altering that part of the maintenance requirement used in respiration. This effect is admittedly small and may be safely neglected for the purposes of this argument). If the maintenance requirement is taken as being constant, then the growth of the fish, proportional to G in the equation, can be seen to vary with food intake in the following manner:

Fig 1.9 RELATIONSHIP BETWEEN GROWTH AND FOOD INTAKE



In order to maximise growth of the trout, it is desired to increase the ratio G/I and to reduce the ratio M/I. M remaining constant, this can be achieved by the simple expedient of increasing I.

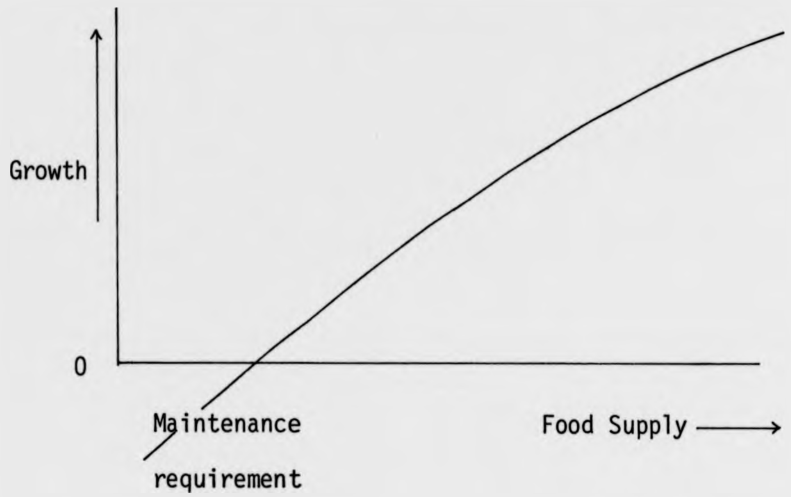
The growth efficiency cannot be increased indefinitely in this manner however for two reasons. Firstly, food intake can only be increased by increasing the food supply up to the level at which the trout's appetite is satisfied, after which increasing the food supply will result in wastage due to food remaining uneaten. Secondly, the efficiency of digestion of trout has been shown to decline at high feeding levels (Frost and Brown, 1967). While it may be possible to increase food intake by increasing the trout's appetite through selective breeding or by artificial stimulation, the growth efficiency will remain limited by the efficiency of digestion unless the two factors are tackled simultaneously. The problem becomes one of finding the feeding level at which the increased efficiency of energy utilisation at a high feeding rate is balanced by the lower efficiency of digestion at the higher feeding rate. Thus instead of the straight line relationship between growth and food intake as shown above, the relationship between growth and food supply is rather of the form shown in Fig 1.10.

Increasing growth efficiency by reducing the ratio M/I may also be achieved by increasing I, or alternatively by reducing the value of M. Good husbandry and health controls may contribute towards lowering this value by reducing the component required for replacing damaged, worn and diseased tissue. Theoretically, M may also be reduced by restricting the activity of the fish (thus lowering the respiratory requirement) as in certain other factory farming techniques.

1.4.5.2 It is therefore the purpose of the manufacturers' charts to achieve a balance between wastage and inefficiency of digestion at high levels and poor growth at low levels of feeding, taking into account all relevant factors such as temperature, food quality, maintenance requirement, size of trout, price of food, price of trout, etc.

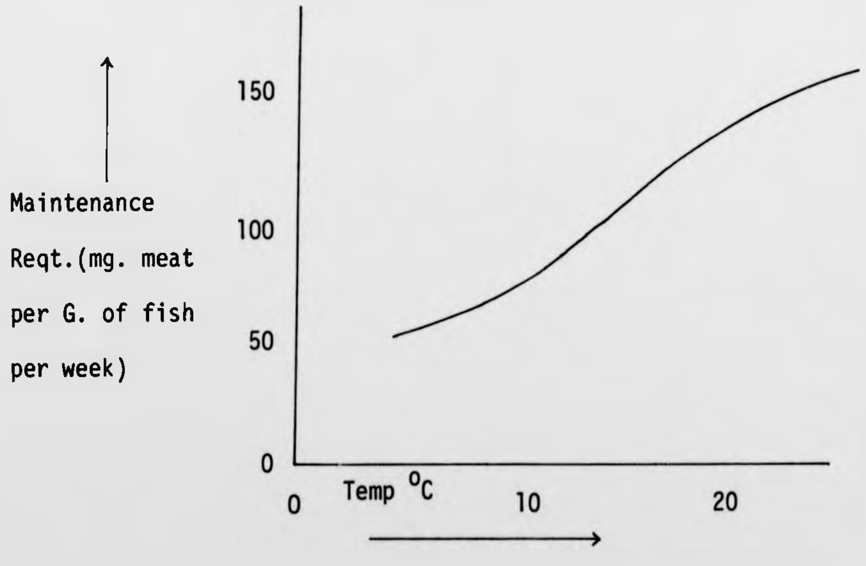
It is not necessarily the case that the feeding level at which growth is most efficient should also be the most economical to the producer, since this will depend on the relative price of the feed and of the trout produced. If the extra growth achieved as a result

Fig 1.10 VARIATION OF GROWTH WITH FOOD SUPPLY



The maintenance requirement varies with temperature in a non-constant manner as shown in Fig 1.11.

Fig 1.11 VARIATION OF MAINTENANCE REQUIREMENT WITH TEMPERATURE. (After Frost and Brown, 1967)



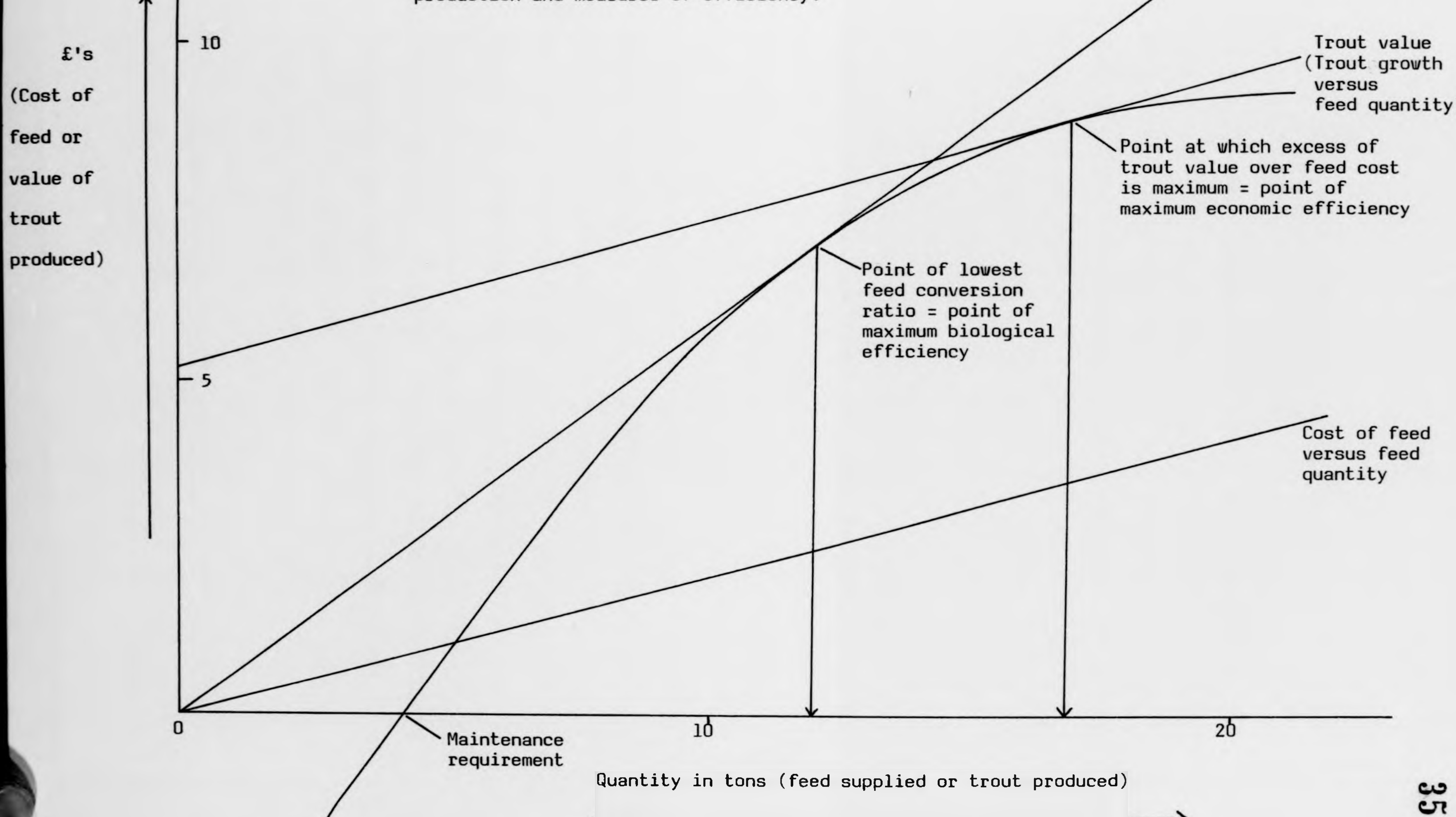


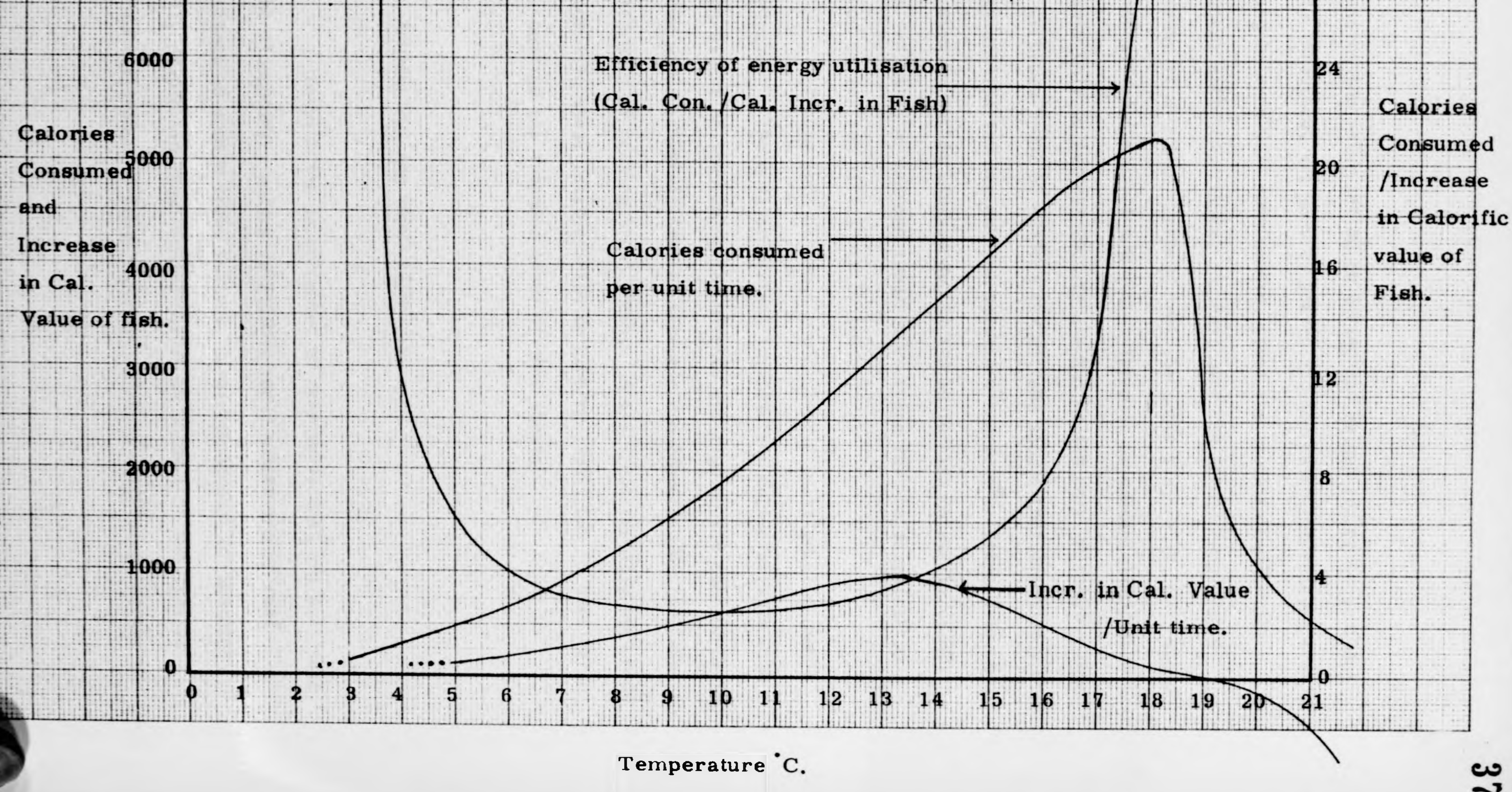
Fig. 1.12. Relationship between quantity of feed, level of production and measures of efficiency.

of feeding in excess of the level of greatest biological efficiency continues to have a value greater than the cost of the feed, then clearly the higher feeding level is justified in economic terms. (Fig 1.12). The point of maximum excess of the value of the trout over the cost of the feed should occur where the value of the trout X the slope of the growth curve is equal to the cost of the feed X the slope of the line relating total feed cost to feed quantity. In practice, however, this relationship is considerably complicated by the effect of other associated farm costs, holding costs, water supply constraints, etc.

As previously stated, trout appear to have well defined appetites and will not eat ad infinitum should food supplies be unlimiting. Where automatic feeders are in use, trout are in a position to satisfy their appetite, but there has been little work done on how well this correlates with the feeding level of maximum biological or maximum economic efficiency. In addition, while there is some information available on the manner in which appetite is temperature dependent, there would not appear to have been much work done on the relationship between feed efficiency and temperature. It would be interesting to assess the economic viability of increasing the growth rate by means of temperature control (using enclosed ponds, solar heaters, etc). Some of the benefits of higher temperature may be inferred from comparisons between farms situated in different parts of the country, although other variables such as water quality and daylength may reduce the value of such comparisons.

1.4.6 Due to the previously illustrated temperature dependent variations in growth rate, it is possible to increase trout production

Graph 1.1. Energy relations for Brown trout at different temperatures.
(After J. M. Elliott, 1976.).



by heating the water inflow in Spring and Autumn and/or to continue growth throughout the year by preventing the water temperature from falling below 4°C. Furthermore, since the trout's food intake increases with temperature, at least over the normal range found in UK ponds, it might be expected that the conversion ratio, G/I, would also be affected since I = M + G. There is at present limited evidence only to suggest that this might be the case, resulting from work on brown trout by Elliott (1976), who showed that efficiency of energy utilisation was optimum between 6°C and 14°C (Graph 1.1), and from work on turbot carried out by the White Fish Authority (1980) which indicated an optimum temperature range for the maximisation of food conversion efficiency by these fish.

Effects such as these could clearly be of great economic consequence. There is at present insufficient data available both on the extent of the biological effects and also on the cost of heating the water to permit here an economic consideration of the benefits or otherwise of heating trout ponds. A start has recently been made in modelling these relationships by Hambrey (1981) but is considered to be outside the intended scope of this thesis.

1.5 AQUACULTURE AND TROUT FEEDSTUFFS

Despite the large number of feedstuffs that are available to the stockholder, only a relatively small number are of real importance in modern trout culture, partly on account of the high quality of protein required and partly on account of the limited geographical range of trout culture, which is restricted largely to the Northern hemisphere where many potential feeds are not available in quantity.

1.5.1 The materials listed in Appendix E are considered to be the most important feed ingredients used in the UK today. All are freely available in quantity although prices are subject to fluctuations, especially for such items as herring meal which depend upon the success or otherwise of the annual harvest. These is however sufficient substitutability between many of the materials (e.g. white fish meal/herring meal; brewer's grain/barley/bran) to enable fluctuations in the price of compound feeds to be ironed out to a large extent. Prices of compound feeds are subject more to the longer term underlying trend in average prices for ingredients in line with inflation and increasing demand.

1.5.2 The composition of a variety of natural trout foods and also of potential live food cultures are recorded in Appendix D, both for comparison purposes with artificial diets and also to enable evaluations to be made of the nutritional adequacy and feed potential of these materials.

1.5.3 A wide range of feedstuffs, either alone or in combination, have been used in aquaculture at one time or another, and a list presented in Appendix C is far from exhaustive. Many of the materials mentioned are however available only in restricted quantities, seasons or locations, and each of these limitations poses a problem to the development of that material as a feedstuff in general usage.

Materials available in very restricted quantities only, such as canned salmon, locust flour, Ceratophyllum, are of little use to the feedstuff manufacturer or in general to the fish farmer, although in certain local situations they may provide a temporary windfall, such as the use of locusts as a feedstuff in South Africa (Farmer's Weekly, 1972). In other cases where the supply is regular but still limited in extent then it may contribute a permanent though minor addition to the diet, such as was the case with the use of the filter washwater from Glenfarg Reservoir in feeding fry at Glenfarg hatchery (Fraser, 1979). Similarly materials available only in isolated localities or available during a short period of the year can only be used economically if an immediate outlet exists locally. If such small scale organic produce can be stored in some way, however, then it may be possible to send it off to a regional collecting/processing centre once sufficient material has accumulated to justify transport costs. As far as most proteinaceous materials of animal origin are concerned, storage in effect requires some prior form of preservation, such as drying, freezing or silage. The various ways of preserving the nutritional value of these materials for use at a later date are briefly discussed in Section 3.1.

Virtually all trout diets currently used in the UK are of the dried pelleted form, offering the fish farmer advantages in storage and handling, and also, being complete feeds, greatly simplifying the feeding routine. The proteinaceous components of such diets are almost always reduced to meal form before incorporation in the pellet mix, the most common materials in use in Western Europe being listed in Appendix E. Other additives - those primarily supplying lipids, carbohydrates, vitamins, etc, such as molasses and cod liver oil - may be added in a variety of forms. All those materials listed in

Appendix E are available on a regular basis and in large quantities, and are accordingly capable of supporting a meal reduction/milling industry, despite the seasonality of some.

1.5.4 While all materials in Appendix E are currently freely available, this is not to say that stability of supply is assured. The fish meal supply in particular is liable to fluctuations, as the twin factors of over-exploitation and government protective legislation influence the landings of industrial fish. Similarly crop-derived feedstuffs fluctuate in supply depending upon the success or otherwise of the previous harvest. This can manifest itself in sharp price fluctuations, especially where imported feedstuffs such as soya are concerned.

The need for alternative feed sources in trout culture is therefore twofold. Firstly the long-term instability of supply of the materials referred to above would indicate the usefulness of potential substitutes. Many of the proteinaceous materials are interchangeable to a certain degree, the extent depending on their respective lipid, carbohydrate and amino acid compositions. The feed processors require to know the extent to which it is possible to substitute one material for another and the relative prices at which such substitutions become worthwhile (the technique used being known as linear programming). The more raw materials there are available to draw from, then the more stable is the system and the price of the final product.

A second reason for developing new feed sources is that the price of high-protein materials is already high in relation to the price of trout and much other livestock. Large increases in feedstuff prices relative to other agricultural products, over a decade when livestock units have tended to become more intensive and therefore more heavily reliant on bought-in feedstuffs, have resulted in some units having to reconsider or partially reverse their policy of intensification, particularly as regards the over-wintering of large stocks of cattle and sheep previously maintained on boughtfeeds in order to more fully utilise the summer growth of the farm.

1.5.5 Trout farming in Britain is particularly vulnerable to fluctuations in feedstuff prices, being almost entirely intensive in nature and not receiving any significatnt contribution from primary production within the unit itself. Furthermore the carnivorous nature of the fish exacerbates the problem, leading to a high requirement for the more expensive animal proteins which cannot be easily substituted. Feeds and feeding have been found to represent about half of the operating costs in a wide variety of aquacultural practices (Huguenin and Annuni, 1977; Collins and Delmendo, 1976; Greenfield, 1969). Easley (1977), however, suggests a figure of around 35% of operating costs, or 29% of total costs, but this is considering an ongrowing unit only, with bought-in fingerlings/fish accounting for some 39% of total costs. Lewis (1979) found that the percentage cost of food varied with the size of the unit (Table 1.4).

This is much as might be expected, food costs in real terms of pence per lb of fish remaining fairly steady throughout the size range, but increasing as a percentage of total costs as the latter are brought down through economies in other areas, particularly labour.

TABLE 1.4 PRINCIPAL COSTS BY SIZE OF OUTPUT (1976) (AFTER LEWIS, 1979)

Output Tons p.a.:	0-5		6-10		11-15		16-20		21-50		100+		All Farms	
No. of farms surveyed:	6		4		5		6		6		4		31	
	pence per lb	%	pence per lb	%	pence per lb	%	pence per lb	%	pence per lb	%	pence per lb	%	pence per lb	%
Fish purchased:	6.8	8.8	13.4	20.7	4.0	6.8	5.5	9.3	5.0	9.6	3.7	9.9	6.4	10.8
Food:	17.9	23.3	15.0	23.1	23.6	39.8	24.9	42.1	19.7	37.5	21.8	57.5	20.6	34.8
Labour:	33.1	43.0	13.2	20.4	15.3	25.8	13.3	22.4	10.4	19.8	4.4	11.6	15.8	26.5
Depreciation:	10.0	13.0	13.2	20.4	6.3	10.5	8.0	13.6	7.7	14.7	2.2	5.8	8.0	13.4
Other:	9.2	11.9	10.0	15.5	10.1	17.1	7.5	12.7	9.7	18.5	5.8	15.3	8.7	14.6
Total:	77.0	100.0	64.7	100.0	59.3	100.0	59.1	100.0	52.4	100.0	37.8	100.0	59.5	100.0

Rising food costs must therefore be paid for by a rise in the price of the trout, failing which UK trout production would be expected to decline as less profitable units fold up.

1.5.6 An agricultural economics survey conducted at Reading University (Lewis, 1979) indicated that in 1976 more than 90% of trout production recorded was from farms producing ten tons or more per annum, although noting that the total estimate of production appeared to be on the low side. Assuming that the smaller units are more likely to be overlooked, it seems likely that the proportion of trout production originating from units exceeding 10 tons per annum is in fact smaller than the 90% suggested. The considerable variety exhibited in UK aquaculture with respect to management system and with respect also to species cultured in the variety of feed types and feedstuff ingredients used.

The vast majority of the larger UK trout farms now use dry compound pellets exclusively, although small scale producers are more inclined to use a variety of locally available cheap animal proteins present in quantities too small to be of interest to larger producers. These cheap animal proteins include materials such as condemned meat, meat offals, fish and shellfish offals, and are used particularly by those producing small quantities of trout for re-stocking and strictly local consumption (river keepers, cottage industries, etc) as a sideline, rather than by those producing substantial quantities of trout as a significant commercial venture. In the past a higher proportion of trout production belonged to the smaller-scale category and the use of offals was more widespread.

Dry compound pellets used in trout farming generally contain between 30% and 54% protein (Appendix A) and cost between

£212 and £570 per ton (January 1980). They are supplied in a variety of forms and sizes, and may be floating, slow sinking or fast sinking to suit the individual circumstances. Much of their popularity stems from their convenience of use with regard to storage, handling and feeding.

Similar pellets are now used in most other branches of UK fish farming, with salmon in particular now appearing to follow a similar trend towards the exclusion of wet diets used previously (MacPhie, 1980). Other species cultured also use dry compound pellets but to a less universal degree. Carp are frequently fed on low protein pellets to supplement a natural diet in semi-intensive culture systems, while eels require a similar diet to trout but appear to prefer a moist paste form of presentation. Dover sole and turbot, farmed on a small scale in Scotland, have special fry requirements for a small live diet and the latter may also be fed on wet fish diets as adults, but there is nonetheless an increasing reliance on compound pellets throughout the main part of the growth cycle.

The overall tendency in the culture of fish in Britain has thus been towards increasing standardisation of feedstuffs, and there are efforts being made at present to design suitable pelleted feeds for sole and turbot that will reduce their dependence on live and fresh foods. In addition EWOS have recently produced a new feedstuff for larval fish, EWOS larvstart, probably directed primarily at the carp market, which it is hoped will replace the use of live feeds in the culture of species with small fry stages. (EWOS, 1980).

For these trends to be reversed, it is probable that alternative feeds should be assured of a regular supply in addition to benefiting the farmer in terms of cheaper feedstuffs or better stock performance.

1.5.7 The current UK aquacultural feedstuff market is dominated by a small number of firms producing a range of pellets varying in size, water stability, density and nutritional characteristics. These proprietary brands are summarised in Appendix A.

Absolute levels of protein are not of paramount importance, since the quality of the proteins, and in particular the amino acid profiles, has a marked affect also on the nutritional qualities of the feed.

1.6 ECONOMICS AND PRODUCTION COSTS OF A TROUT UNIT

The manner in which trout production costs may be broken down into items such as food cost, labour and depreciation depends very much on the type of system in use and on the scale of the enterprise. While feed costs may be high in intensive culture systems they will be very much lower in semi-intensive systems and non-existent in extensive systems. Conversely, for an equal volume of trout production the rental or opportunity cost of land taken up in extensive culture would be many times that required by an intensive system.

Extensive and semi-intensive methods are little used in the UK. Lewis (1979) states that ten trout farmers out of a total of eighty correspondents in 1976 indicated that they were using natural ponds as a means of production, and two that they were using natural streams, either alone or in conjunction with other systems. Of the ten, six were producing less than five tons p.a. Note also that the use of natural water bodies does not in itself exclude the possibility of culture being intensive.

There is little doubt therefore that by far the greatest proportion of current production is from intensive systems, production being divided between excavated ponds, tanks, raceways and cages in descending order of importance (Lewis, 1979). In addition to favouring different pellet types (as indicated in Section 1.3.2.4) the system used indirectly affects feed costs as a percentage of total production costs by its affect on the depreciation component of production costs. Lewis investigated the relationships between costs and size of unit and costs and production systems. His findings are summarised in Tables 1.5 and 1.7.

This domination of the industry by a relatively small number of larger producers, as indicated in Table 1.7, has probably continued to the present although it is poorly documented in view of the natural tendency of such surveys to overlook the very small producers.

The size structure of the industry is of importance on account of the affect on the ratio of production cost breakdown items. This is particularly marked in the economies of scale evident in labour costs and depreciation (Table 1.7). Feed costs on the other hand remain fairly constant in absolute cost per unit of production, but as a percentage of total costs feed costs tend to occupy an increasingly important place, rising from around 23% of total costs for farms producing less than 5 tons to some 57% of total costs for those producing over 100 tons per annum, while labour drops from 43% to 23%. Any new feed item that may be proposed must clearly therefore take into account the affect upon labour requirements and other associated feeding costs. While the incorporation of new meals in an otherwise similar compound pellet to that already used will not affect these associated cost items of culture being intensive.

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TABLE 1.5 AVERAGE RETURNS, COSTS AND MARGINS BY OUTPUT SIZE (AFTER LEWIS, 1979)

Group Size (Tons p.a.):	0-5	6-10	11-15	16-20	21-50	100+	All
Fish sales + final valuation - initial valuation (pence/lb):	67.2	69.8	64.8	65.9	54.7	51.5	62.5
Total Variable Costs (pence/lb):	29.6	32.1	31.9	35.5	29.6	26.9	31.3
Total Fixed Costs (pence/lb):	47.4	32.6	27.4	23.6	22.8	10.9	28.2
Total Costs (pence/lb):	77.0	64.7	59.3	59.1	52.4	37.8	59.5
Margin (1) (pence/lb):	-9.8	5.1	5.5	6.8	2.3	13.8	3.0
Minus Paid Management (pence/lb):	-	-	-	-	2.7	0.5	0.6
Plus Unpaid Labour included in fixed costs (pence/lb):	26.2	3.6	7.8	1.3	-	-	7.1
Margin (2) (pence/lb):	16.4	8.7	13.3	8.1	-0.4	13.3	9.5
No. of farms in study	6	4	5	6	6	4	31

TABLE 1.6 AVERAGE PERCENTAGE COSTS BY OUTPUT SIZE (AFTER LEWIS, 1979)

Group Size (Tons p.a.):	0-5	6-10	11-15	16-20	21-50	100+	All
Variable Costs % Detailed Below):	38.4	49.6	53.8	60.1	56.5	71.2	52.6
Fish Purchases:	8.8	20.7	6.8	9.3	9.6	9.9	10.8
Food:	23.3	23.1	39.8	42.1	37.5	57.5	34.6
Contract Labour:	0.1	1.4	0.7	3.3	2.7	-	1.5
Packaging:	0.8	0.3	1.8	1.6	1.9	0.8	1.2
Transport	3.6	2.5	4.4	3.4	4.2	2.5	3.5
Miscellaneous:	1.8	1.6	0.3	0.3	0.6	0.5	0.8
Fixed Costs % (Detailed Below):	61.6	50.4	46.2	39.9	43.5	28.8	47.4
Regular Labour:	8.9	13.5	11.9	16.7	17.1	11.6	13.1
Unpaid Labour:	34.0	5.5	13.2	2.3	-	-	11.8
Maintenance, Insurance and Administration:	4.7	9.0	9.3	4.7	10.1	8.5	7.2
Depreciation:	13.0	20.4	10.5	13.6	14.7	5.8	13.4
Power & Fuel:	0.9	2.0	1.4	2.7	1.7	3.0	1.8

TABLE 1.7 OUTPUT BY FARM SIZE, 1974-1976 (AFTER LEWIS, 1976)

Group size (Tons p.a.):	1974		1975		1976	
	No. of farms	Output t.p.a.	No. of farms	Output t.p.a.	No. of farms	Output t.p.a.
0-10	31	111	41	157	51	185
11-20	4	57	7	104	12	178
21-50	9	308	9	305	13	437
51+	7	1,045	11	1,309	13	1,544
Total:	51	1,521	68	1,875	89	2,344

at all (or marginally if the new constituent affects pellet density, water stability, etc), the use of wet feeds would probably greatly increase assosciated costs involved with handling and storage. In an initial screening of items for further study, discussed in the following chapter, these assosciated costs were not taken into consideration, but should be included in later stages of cost appraisal.

1.7 OUTLINE OF THE THESIS LAYOUT

Table 1.6 clearly identifies food costs as the single most important cost centre in UK trout culture, and provides the justification for looking at this particular aspect first in any attempt to improve the profitability of the industry.

Essentially there are two main options open in the reduction of feed costs, these being either to reduce the costs of ingredients or to make more economically efficient use of existing feedstuffs. In the following text, Chapters 2 to 5 investigate the potential for the reduction of ingredient costs by the development of cheaper alternatives, while Chapter 6 considers the possibility of increasing the economy of use of existing and alternativeingredients. In many respects the two approaches are inextricably linked, and Chapter 7 therefore attempts to provide an overall view of current prospects on the basis of what is described.

CHAPTER 2

Trout feedstuffs and feed requirements

2.1 DIRECT AND INDIRECT FEEDSTUFFS

The materials considered in this thesis have, for the sake of convenience, been divided into two categories, "direct" and "indirect" feedstuffs.

The former is taken to include those materials which, either alone or in combination, may be fed directly to trout without the need for any further biological processing. These materials are generally high in protein content and of animal origin, and are considered as potential substitutes for the expensive animal protein component (white fish meal, blood meal, etc) of compound trout pellets.

Indirect feedstuffs are taken to mean those which are not incorporated in the trout diet itself but could conceivably be used to culture other proteinaceous organisms for use as trout food. These materials include manures, sewage and crop residues.

A number of the materials may however fit into either category, e.g. fish offal, activated sewage sludge, etc, and as such may be considered under either or both sections.

2.2 SELECTION OF MATERIALS FOR STUDY

A vast range of organic substances are available, nearly all of which could potentially be used as a feedstuff. Accordingly it was felt necessary to eliminate all but the most promising of these from the outset to limit the work to manageable proportions. This was considered to be best achieved by matching all candidates against a simple set of criteria.

2.2.1 The major attributes of a potential feedstuff may be broadly summarised as follows:

- It should be cheap
- It should be nutritious
- It should be non-toxic
- It should be acceptable to the fish
- It should be widely and regularly available
- It should be plentiful
- It should be acceptable to the consumer

The twin criteria of cheapness and nutritional quality were considered to be of primary importance, and it was taken as a prerequisite of further study that a proposed material should satisfy the condition that the price of the new material multiplied by the known or expected conversion factor of that material into trout tissue should be similar to or less than the price of existing feed materials multiplied by their relevant conversion factors (Sections 2.3 and 2.4). Where the material is being considered as a potential culture medium for a food organism, rather than as a feedstuff in its own right, the conversion factor of the material to trout becomes the product of the conversion factor of the material to food organism and the conversion factor of the food organism to trout. This sets an upper limit on the price of materials giving average conversion factors (in the range 6-10 for most wet feeds) as between £50 and £100 per ton for materials to be fed directly to trout and £5-£20 per ton for materials being fed via some intermediary 1980-1981 prices). Naturally a higher price can be afforded for those materials of higher nutritional quality producing lower conversion factors, hence the difficulty of treating these two criteria separately.

Materials known to be toxic from the literature were eliminated unless an effective means of counteracting the toxicity had already been demonstrated or appeared likely. Certain items however may exhibit deleterious effects only when fed to stock over a period of time, due to dietary deficiencies or imbalances, while others may prove simply unpalatable to trout. In order to provide more information on certain of the materials studied, a number of feeding trials were set up using rainbow trout in a number of concrete ponds (see Section 2.2.2).

Availability is of major importance if a material is to achieve widespread and large scale use, and is therefore to be desired. Nonetheless, certain materials available only on a small scale or on a local basis may still prove useful to individual fish culturists, and these criteria are therefore considered of lesser importance. Regular availability on the other hand may be considered of rather more importance on account of its affect upon storage and transport requirements and hence its affect upon the prime criterion of cost. Note also that availability is, perhaps more than any other criterion, markedly sensitive to many other factors, and it is perhaps potential availability that we should be considering should a suitable market for the item be demonstrated.

Acceptability to the market consumer is highly intangible and does not receive detailed attention in this thesis except for a subjective assessment in Section 2.2.2 and a brief consideration in the concluding discussion sections. It is perhaps therefore not properly considered as a selection criterion and was not so used. Acceptability concerns such factors as tainting of the trout flesh, risk of pathogen transmission, and consumer resistance, and may apply to both direct and indirect (cultured) feed materials.

2.2.2 In order to provide information on certain aspects of some of the proposed novel feed materials, a number of simple feeding trials were conducted in a series of rectangular 75 gallon concrete ponds for the purpose and fed from a spring water supply, previous indoor aquarium facilities having proved inadequate (Fig. 2.1). The main purpose of these trials was to provide basic information on the extent to which a material met the criteria outlined in Section 2.2.1 in order to suggest whether a material merited further more detailed study, and values given are approximate only in many cases limited by the weighing facilities.

In general, rainbow trout were fed to satiation twice daily, on materials discussed in the text, over periods of up to three weeks duration, and quantities of feed consumed, growth of the trout, and apparent acceptability of the diet were observed. (See Tables 2.1 and 2.2).

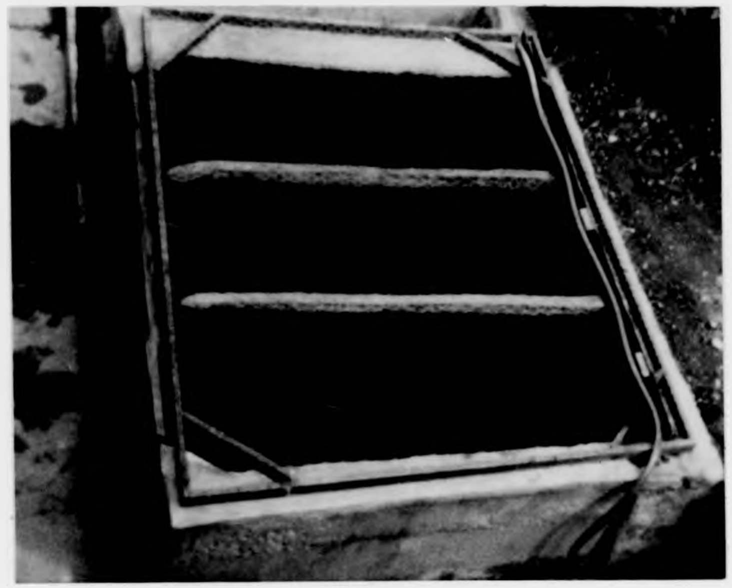
Up to three materials could be investigated in this fashion at one time, but due to limited experimental resources the same fish were used in successive trials. In order to minimise the effects of previous dietary history on subsequent feeding trials, the fish were intermixed and fed for longer periods of a month or so on a standard compound pelleted diet (E.W.O.S. Trout Grower No. 4) in between trials.

A number of shortcomings of this approach were recognised, deriving principally from the limited experimental resources available, and attempts were made to overcome them:

- The period involved in most of the trials was short and in many cases trials were not duplicated. However, experimental results from other authors were available for the majority of the materials studied, to serve as a check and to suggest further experimental work were any unexpected results to be found.

- The experimental food materials were in many cases scarce and hence the quantities involved were often small. This applies in particular to many of those organisms suggested for culture, particularly the various aquatic detritivores, in which substantial cultures would have to be maintained to supply even relatively modest feeding trials. The effect of the small quantities of test material was reduced to some extent by using small (3" trout) such that growth might be more easily observable, although in many cases it was not practical to record the weight of food consumed.
- The effect of differing dietary histories was not entirely eliminated, although it was reduced as already mentioned by "resting" the fish in between trials and mixing them with fish from other trials or from reservoirs of stock not involved in current trials.
- The trials were conducted over a period of some months in Spring and Summer 1979 and again, with new stock, in 1980. Consequently the stage of development of the fish and climatic conditions varied to some extent, although this variability was probably reduced to some extent by a certain stability of temperature in the spring water supply. It is of course reasonable to suppose also that certain of the items might be expected to prove more suited to particular sizes of fish, e.g. the small size of Daphnia might favour their use for a small size of fish.

Fig. 2.1. Experimental ponds used in acceptability trials.



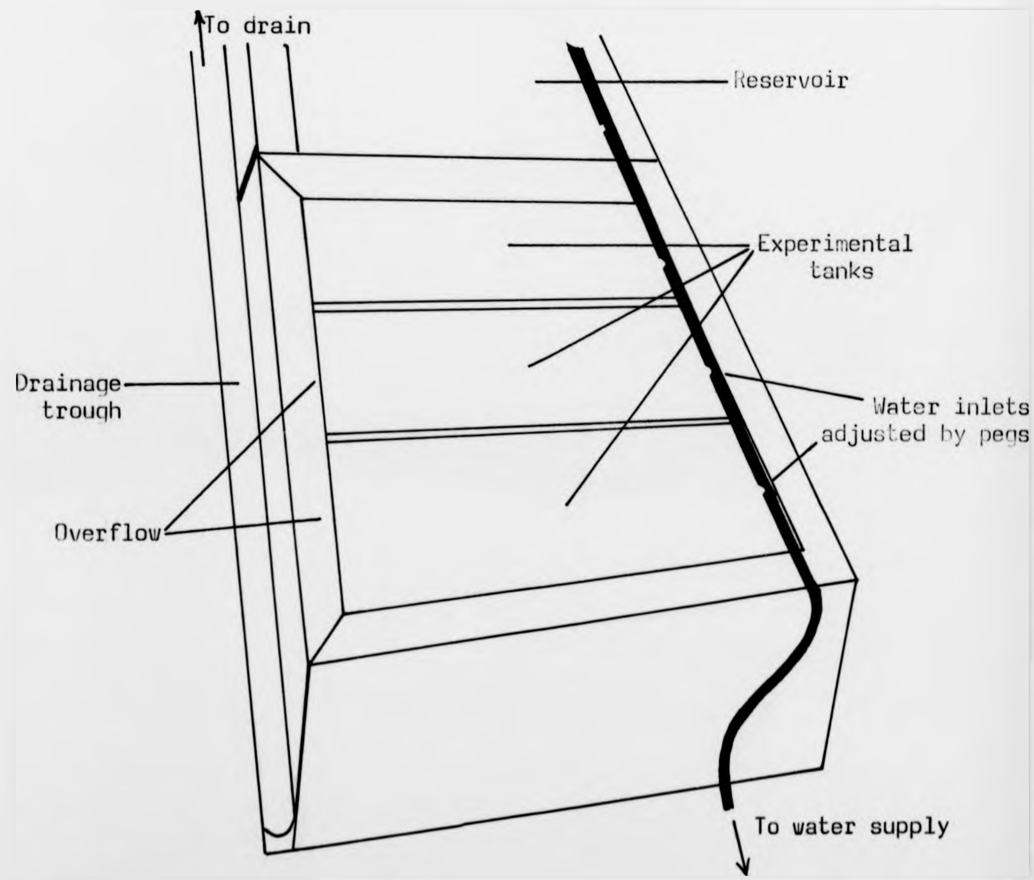
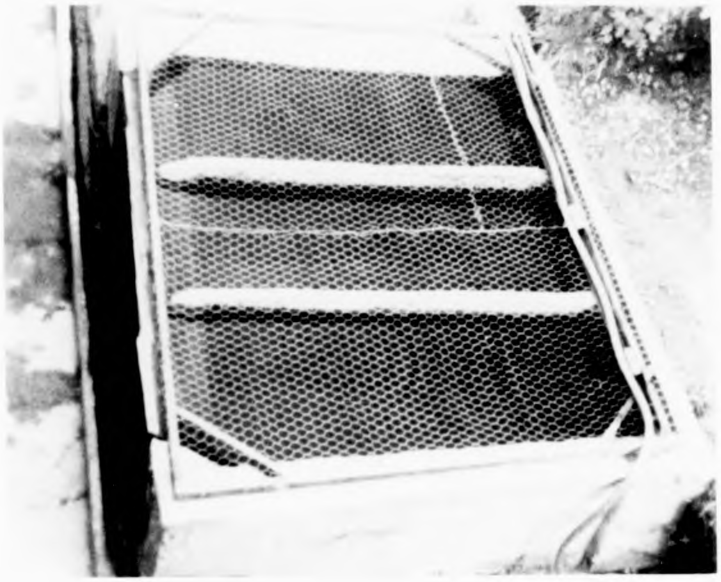


Fig. 2.[illegible]. Experimental ponds used in acceptability trials.



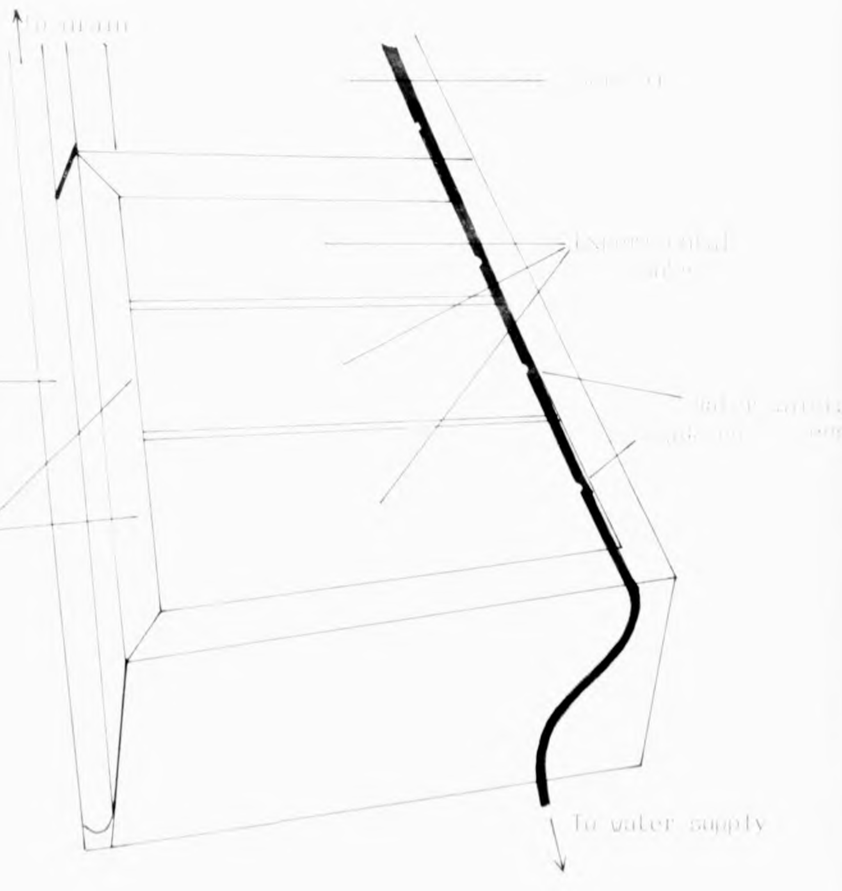


TABLE 2.1 FEEDING AND ACCEPTABILITY TRIALS

Item	Duration (days)	No. of Fish	Agg. wt. at start (g).	Agg. wt. at end (g).	Agg. wt. of food cons.(g)	Conversion (where applicable)
L. terrestris	21	33	401	511	749	6.8/1
L. rubellus	21	35	403	504	701	6.9/1
M. domestica	10	12	1193	50% mortality - trial		
M. domestica	10	11	1164	abandoned		
Mytilus edulis	21	11	451	574	747	6.1/1
M. edulis plus	14	10	438	532	363	N.A.
pellets					70	
T. saltator	5	10	121	128	42	6.0/1
Termite Sp.	5	5				
Daphnia Sp.	"	"		QUANTITIES TOO SMALL TO BE		
Chironomid Sp.	"	"		ACCURATELY MEASURED - LIVE		
Gammarus Sp.	"	"		FOODS MAINTAINED IN TANK		
Tubifex Sp.	"	"		WHERE AQUATIC.		

TABLE 2.2 APPROXIMATE CONSUMPTION

ITEMS

	L. terr.	L. rub.	M. dom.	M. dom.	Mytilus edulis	Mytilus edulis plus pellets	Talitrus saltator
Start Date	3/8/79	3/8/79	9/3/79	9/3/79	5/6/80	5/6/80	19/6/80
Day No.							
1	32	28	87	63	40	27/5	7
2	39	34	43	60	42	22/5	10
3	31	29	40	52	38	24/5	9
4	38	33	33	41	38	21/5	7
5	36	33	36	51	41	23/5	9
6	38	34	24	36	32	28/5	
7	24	30	30	24	34	21/5	
8	30	36	17	28	39	31/5	
9	40	31	9	19	31	27/5	
10	33	37	4	21	38	23/5	
11	38	36			41	30/5	
12	32	35			36	29/5	
13	36	31			40	30/5	
14	39	29			33	27/5	
15	42	33			33		
16	41	35			36		
17	36	31			32		
18	29	38			30		
19	41	32			27		
20	40	33			31		
21	34	33			35		
Total	749	701	323	395	747	363/70	42

It is considered that the main purpose of these trials, viz. to expose any materials which were either toxic or unacceptable to the trout or which failed to promote growth or maintain condition in the fish, and so to provide a basis on which various of the materials might be compared against those criteria drawn up in Section 2.2.1, was not seriously undermined by these drawbacks. Trials were also conducted on a number of other materials which had already proved to be of demonstrable use in fish culture and for which vital parameters were already recorded in the literature (e.g. fish, meat offals, etc). In these instances, weights consumed were not recorded and subjective estimates only were made concerning the apparent acceptability of the diet and the growth rate resulting from satiation feeding.

All the materials used proved acceptable to the trout when fed as an exclusive diet, although with some marked variations in palatability. None of the materials which appeared suitable from the point of view of price and nutritional analyses were excluded from further study on the basis of toxicity or unpalatability, although reservations regarding certain of the materials are noted in the relevant sections of the text. It is also noted that where a material is intended as a potential medium for the culture of an intermediate food organism, then it is the acceptability of the cultured item that must be demonstrated. Toxic ingredients however are frequently transferred through the food chain and would therefore be of relevance in either the raw material or the intermediate cultured items. Furthermore acceptability to the consumer may apply both to the intermediate organism or to the raw material on which it is cultured.

On the basis both of the trials described here and from reports elsewhere in the literature, materials suggested for study were

TABLE 2.3 DIRECT MATERIALS MATCHED AGAINST SELECTION CRITERIA

Material	Price	Nutr. Qual.	Toxicity	Accept. to Fish	Growth of Fish	Conversion	Avail.	Accept. to Cons.
Industrial fish and offals	Low -Medium	V.Good	-	Good	Good	Good	Wide, Plentiful	Good
Shellfish offals	Low	Poor	-	Good	Poor	Poor	Local	Good
Mussels	High	V.Good	-	V.Good	V.Good	Fair	Wide, Plentiful	Good
Krill	High	Good	-	Good	Good	Good	Potentially plentiful	Good
Meat and offals	Medium -High	Good	-	Good	Good	Fair	Wide, mod. quantities	Good
Seal meat	Medium -High	Good	Uncertain	Not known	Not known	Not known	Local, mod. quantities	Uncertain
Blood (fresh)	Low -Medium	Good	Possible amino acid imbalance	Fair	Fair -Good	Fair -Good	Wide, mod. quantities	Fair
Brewers' and Distillers' Res.	Medium -High	Fair	-	Fair	Fair	Poor -Fair	Wide, Plentiful	Good
Single cell protein	High	Fair -Good	Possible nucleic acid imbalance	Variable	Fair -Good	Variable	Wide, Plentiful	Fair -Good
A.S.C.P.	V.Low	Fair	Uncertain	Fair	Fair	Fair	Wide, Plentiful	Poor

TABLE 2.4 CULTURED AND INDIRECT MATERIALS MATCHED AGAINST SELECTION CRITERIA

Cultured Materials	Nutr. Qual.	Accept. to fish	Tox.	Growth	Accept.to Cons.	Culture Mediums	Price	Nutr. Qual.	Tox.	Avail.	Accept. to Cons.
L. terrestris	Good -V.good	V.good	-	Good	Fair	Animal Manures	V. Low	Fair	-	High	Poor
L. rubellus	Good -V.good	V.good	-	Good	Fair	Solid Sewage Sludges	V. Low	Fair	Possible	High	V.Poor
E. foetida	Good	Good*1	Poss.	Good	Poor -Fair	Active Sewage Sludges	V. Low	Fair	Possible	Moderate	V. Poor
M. domestica	Fair	Fair	Poss.	Poor*2 -Fair	Poor -Fair	Offals	High	High	-	Moderate	Fair
T. Saltator	Good	V.good	-	Fair-Good	Good	Algae and Seaweeds	Medium	Fair	-	Moderate	Fair -Good
Gammarus	Good	V.good	-	Fair-Good	Good	Aq. Weeds	High	Fair	-	Small	Fair -Good
Misc.Aq.Detritvrs	Good	V.good	-	Good	Fair -Good	Leaf Falls	Medium	Poor -Fair	-	Small	Fair -Good
Termites	Fair	Good	-	Fair?	Fair	Crop Residues	Medium -High	Fair	Some Residues Toxic	Moderate -High	Good
						Timber Residues	Medium	Poor	-	Moderate	Good

*1 Not all reports would agree with respect to this item

*2 In own trials, results were very poor matched against the criteria outlined in Section 2.2.1 as summarised in Tables 2.3 (direct materials) and Tables 2.4 (cultured and indirect materials). Only those materials which largely satisfied the criteria are included in these tables since there would be little point in showing the very large number of outside possibilities which failed to come anywhere near the requirements.

2.2.3 A large number of organic materials were listed as potential candidates from which the following were selected for further investigation as alternative feeds or feed culture materials on the basis of matching the simple criteria outlined:

<u>Direct Materials</u>	<u>Indirect Materials</u>
Industrial fish and fish offals	Timber residues
Mussels and shellfish offals	Crop residues
Krill	Leaf falls
Blood and slaughterhouse offal	Aquatic weeds
Seal meat	Algae and seaweeds
Distillers'/brewers' residues	Solid sewage sludges
Yeasts	Activated sewage sludges
Activated sewage sludges	Animal manures
Single cell petro-proteins	Offals

It is accepted that the method of selection outlined above has severe limitations, in that a number of materials excluded from study could conceivably become of value in the event of changed circumstances, e.g. price changes, technological improvements, etc. This unfortunately cannot be avoided without enlarging the scope of the work and thus diverting attention from more promising materials.

2.3 ECONOMIC CONSTRAINTS WITH REGARD TO DIRECT MATERIALS

2.3.1 Profit margins in the UK trout farming industry are at the time of writing being held down to some extent by the relatively high cost of feedstuffs and do not appear to be high for the risks involved in the business, although those units that succeed in avoiding any of the major calamities - flood, disease, water flow failure, etc - may still make a fair margin in the region of 10%-20%.

The industry has been becoming increasingly competitive in recent years, with demand apparently failing to keep pace with rising production. Feed costs have risen greatly over the last decade and this has not been fully compensated by increases in the price of trout or by improvements in the quality of the feed. As regards the fish farmer, the most important consideration concerning a feedstuff is that it should combine cheapness with good conversion to produce a given weight of trout at the lowest possible cost of feed input, although this is modified by other factors such as growth rate, trout quality, etc. Feedstuffs tending to produce better quality trout may command a premium, particularly for stock fish, brown trout and broodstock. In general terms, however, for an alternative feedstuff to replace a conventional pelleted feed the following primary condition should be satisfied:

$$\text{Price} \times \text{Conversion Factor (New Feed)} \leqslant \text{Price} \times \text{Conversion Factor (Old Feed)}$$

This assumes for the moment that other costs associated with the two feeds (storage, handling, etc) are equal. Such associated costs will be more fully considered in later sections on individual materials. Here it is desired to examine the feed cost in isolation.

Taking compound pelleted feeds as the feed in use on the right hand side of the equation, current (March 1980) prices for trout pellets (growers) range between £250 and £400 per ton (e.g. Omega (Trout Growers, Slow Sinking) Nos. 5 and 6; £279 per ton: Tess (Trout Growth Feed) No. 3-4; £380 per ton). Feed conversions in practice tend to fall between 1.2 and 2.0 (higher conversion efficiencies recorded in trials are seldom found in farm scale operations). There is little detailed information available on the conversion efficiencies achieved using the various diets on the market tested under strictly comparable conditions, although many established farms will have formed opinions as to the respective merits of the brands from their own records. A published study of this nature would be welcome to many people, especially those starting new units. At present such evidence as exists indicates, as one might expect, that the high priced and high quality (high protein content and/or high animal protein/vegetable protein ratio) pellets tend to produce the lower conversion factors and vice-versa, such that the product of Price X Conversion Factor should not differ greatly, under normal circumstances, from one feed to another. (This should not be taken to imply that the brand of feed used is unimportant, but only that our knowledge of which gives the best value is insufficient.)

Thus:

Price X Conversion Factor (New Feed) $\leqslant$ £(250-400)(2-1.3) $\leqslant$ £500 per ton of trout produced.

Where the new feed is itself intended to form the complete diet, it is only necessary to know the conversion factor to be expected in order to be able to place a maximum price on the new feed itself, above which the alternative feed is unlikely to be worth considering:

$$\text{Price of new feed} \leqslant \frac{\text{£500 (at current prices)(1980)}}{\text{Conv. Factor using new feed}}$$

In practice, the "less than or equal to" rider may be replaced simply by "less than" since there is little point in incurring the trouble that a change of feedstuff entails if significant benefits are not expected.

Thus for fresh sea fish, giving a conversion factor generally in the region of 5-7/1, the maximum price at which it is worth considering their use is around £70-£100 per ton. This does not take into account such feed associated costs as handling, storage and transport, which in this instance mitigate against the use of fish at this price (see later section on this material).

The foregoing applies only to those materials being considered as a complete feed in their own right. Where the material is not intended as a complete feed, but rather as a constituent of a formulated diet, then the term "conversion factor" rather loses its meaning as applied to constituents within the diet as these will all vary depending on their respective inclusions, as well as being more complicated to measure. For evaluating such materials as these, therefore, the technique of linear programming is used to assess the merits of a particular material being investigated in combination with those other materials in common use in feedstuff preparation. High protein levels, and particularly high levels of otherwise limiting amino acids, add greatly to the value of such a material for compound use. The value determined by the technique of linear programming is essentially the cost at which the material would become economically competitive with those materials in established used.

2.3.2 The foregoing section on general economic considerations of fish feeding refers to feedstuffs used as a primary constituent in diets used during the main ongrowing stages of the fish. In many of the examples of live foods cultured as fish feeds in following chapters the material is intended as a first feed only, especially for fish whose small larval/fry stages do not permit the initial use of pelleted feedstuffs.

In such circumstances, the rapid development and good survival of the fry is of major importance, and a superior feed, due to the relatively small quantities used, may fetch a very considerable premium over those feeds used in the main growing phase. Hence many food items are cultured as larval/fry feeds that would not be considered economically viable as a main food item for the fish during the ongrowing stages.

Trout fry are far larger than the fry of many other cultured fish species, and may accept pellets immediately after the absorption of the yolk sac, considerably lessening the need for special larval diets. Trout fry diets nonetheless may still command a substantial premium of some 50-60% over standard growing pellets, generally on account of higher protein levels (See Appendix A).

2.3.3 Certain materials have been reported to influence fish growth to a degree greater than may be explained by the known nutritional contribution of the material. These are said to supply unidentified growth factors, usually known as U.G.F., to the diet.

Where materials are believed to contribute unidentified growth factors in this manner, it is no longer realistic to evaluate the item by linear programming on the basis simply of its known nutritional contributions (as reported in Appendices C, D and E) to the diet, since the unknown nutritional contributions are of such importance in these circumstances. Such items can therefore only properly be evaluated on the basis of their effectiveness in practice.

For illustrative purposes only,the economic contribution with regard to certain hypothetical examples are demonstrated in Appendix L.

None of the feeds investigated were suspected of promoting growth to an abnormal degree, however, and all were evaluated according to the conventional methods outlined in this chapter.

2.4 ECONOMIC CONSIDERATIONS WITH REGARD TO INDIRECT MATERIALS

2.4.1 The term indirect materials is here used to describe all those which may be used in the culture of food for trout but are not used directly, and as such includes manures and crop residues as well as sewage sludges and fish offals where these are being considered as a substrate for the production of other proteinaceous organisms rather than as a direct feed themselves.

In this and the following sections the cultured material to be fed to the trout is referred to as the intermediate organism while the organic substrate is referred to as the raw material.

TABLE 2.5. RECORDED CONVERSION QUOTIENTS OF FOOD ORGANISMS AND MATERIALS INTO TROUT FLESH

Item	Conversion	Source/Reference
Gammarus	6.6/1	Surber, 1935: Pyle, 1965
Gammarus	5.0/1	Pentelow, 1939
Gammarus	3.9/1	Cornelius, 1933
Chironomus Larvae	4.4/1	Cornelius, 1933
Maggots (M. domestica)	7.1/1	Phillips et al, 1956
Earthworms (E. foetida)	7/1	Section 5.3
Earthworms (L. terrestris)	7/1	Section 5.3
Freshwater Fishes	2.9/1	Cornelius, 1933
Seawater Fishes	5-7/1	Bregneballe, 1963
Beef Liver (Fresh)	2.9-3.3/1	Phillips et al, 1956
Spleen (Fresh)	2.9/1	Cornelius, 1933
Fresh Meat	3.0/1	Schaperclaus, 1961
Oregon Moist Pellets	2/1	Hublou, 1963
Fish Flour	1.5-3.0/1	Hickling, 1974
Cooked Meat Offals	5-8/1	Hickling, 1974

An upper limit to the price of the intermediate organism may be obtained according to the same formula as that pertaining to direct feedstuffs:

$$\text{Price X Conversion Factor (Org/Trout)} \leqslant \text{Price X Conversion Factor (Existing Feed)}$$

In order to assist with the resolution of this equation, expected conversion factors (organism/trout) for a number of proposed intermediate organisms and direct materials have been collected together in Table 2.5.

In similar fashion to direct materials, organisms that are considered not as a complete feedstuff but as a component of a compound feed may be evaluated by linear programming techniques.

However, the intermediate organism represents an additional link in the food chain, and the minimum price of the organism theoretically obtainable (if labour, heating costs, etc could be reduced to negligible proportions) is governed by the price of the raw material X the conversion factor for raw material to intermediate organism, and the maximum price at which a material is considered worthy of further attention for the purposes of this project is given therefore by:

$$\text{Price of Raw Material} \leqslant \frac{\text{Existing Feed Price}}{\text{Conv. Factor Org/Trout}} \Big/ \begin{matrix}\text{Conv. Factor}\\ \text{Raw Mat./Org.}\end{matrix}$$

Thus to take manure-cultured worms as an example,

$$\text{Price of Manure} \leqslant \frac{\text{£500 (See 2.3.1)}}{7^{*}b} \Big/ 10^{*}a$$

*a Conversion Factor Manure/L. terrestris. (Spedding, 1974) *b Conversion Factor Worms/Trout. (Table 2.5.)

i.e. the price of the raw material in this case should be less than £7 per ton in order to be considered further.

Associated costs are twice neglected in this case, once in producing the intermediate organism and again in producing the trout. Many materials that are cheap enough to be considered as a feedstuff on the simple basis of conversion factor comparisons cease to appear feasible when these other factors are allowed for in later sections, and the cut-off price of raw materials is used as a screening device only to concentrate attention on the more promising materials.

2.5 EVALUATION OF MATERIALS AS PROTEIN CONTRIBUTORS IN COMPOUND DIETS

2.5.1 A number of live or cultured feeds are nutritionally adequate to promote good growth in rainbow trout when fed either alone or with added vitamins only, especially if fed as mixed species. Other live feeds may prove to be beneficial as a supplementary growth-promoting feed or as a fry feed. Where live feeds are intended as a major growth feed, however, it would in many cases be advantageous to feed them in conjunction with a suitably adjusted mixture of other conventional feedstuffs, either on account of these other materials being relatively cheap (e.g. the "vegetable portion" of dry compound diets, the animal protein being supplied by the live diet) or to compensate for nutritional deficiencies in the cultured item. In such cases the live cultured materials under consideration cannot be properly evaluated on the simple basis of the conversion ratio achieved when trout are fed an exclusive diet of these materials. Therefore the technique of Linear Programming is used to ascertain the potential value of a number of cultured or naturally occurring feeds which may be either fed live but complemented by an incomplete compound diet (the limitations of this system are discussed further in a later section on the use and formulation of moist pellets), as a fresh wet component of a moist pelleted feedstuff, or as a component of a dry compound feedstuff should this last appear economically attractive.

It was decided to evaluate these materials primarily as a source of protein and essential amino acids. This is because this project is principally concerned with the investigation of alternative protein sources, animal protein in particular being in short supply; because the nutritional requirements of salmonids for dietary protein and essential amino acids is very much better understood, and the data therefore more reliable, than is the case for fats, oils and essential fatty acids or carbohydrates and fibres; and because data on the fatty acid content of naturally occurring and /or cultured organisms is in many cases not available. Certain possible advantages of the items evaluated - vitamin content, presence of unidentified growth factors, etc - are therefore not taken into consideration by this program. The limitations of this program are fully appreciated, but it is nonetheless considered that the values suggested are reasonable given the current state of our knowledge regarding trout feeds.

The program package used was MPOS, contained in the library of the University of Manchester Regional Computer Centre. The declared objective of the exercise was to minimise the cost of a diet based upon conventional and novel ingredients and subject to the constraints imposed by the nutritional requirements of the trout, and hence, by testing only one novel ingredient at a time, to estimate the price at which the novel feedstuffs could compete with established ingredients.

In order to achieve this it is necessary to provide the program with data on the requirements of the trout for specific nutrients and on the contribution made to these nutrient levels by the individual feed ingredients. Appendix G summarises this data in the following manner:

Items X1 to X20 are common and established feed materials, and supply the basal ration from which a compound ration may be formutated. (The labels X1 to X20 are those used in the input equations to the program, and are used to link up with the input cards and the printed output and are included in the table presented in Appendix G to facilitate cross-referencing only). The L.P. evaluation was based on dry matter, and the nutrient compositions summarised are based on 100% dry matter and do not therefore coincide with compositions given for the same materials in Appendix E, which are based on analysis of the material as bought, including any usual hydration levels. The contribution of specific nutrients is then calculated from the estimated digestibilities derived in section 2.7.

Items labelled X21 are novel protein materials that it is wished to evaluate. Again the nutrient compositions summarised are based on 100% dry matter and do not therefore coincide with compositions given for similar but hydrated materials in both Appendix E and Appendix D. All of these items were included in the basal ration independently of one another but in conjunction with items X1 to X20, against which they are evaluated. The nutrient contribution was calculated assuming both 80% and 90% protein digestibility of the novel material, giving alternative valuations, on account of the fact that the actual digestibility of these items is poorly known.

The nutrient requirements of the trout are also based on 100% dry matter, and are derived from section 2.6 which summarises the nutrient requirements of the trout.

Data on the contribution made by the ingredients listed in Appendix G are based where possible on nutrient analyses obtained from the literature and adjusted for digestibility as indicated in Section 2.7. Where nutrient analyses were not available in the literature, however, analyses were conducted either by the author, using a Perkins-Elmer analyser, or on behalf of the author by Dr Ambler of the Edinburgh University Department of Molecular Biology, who supplied the amino acid analyses. The sources of the data used are fully referenced in the relevant tables and appendices.

2.5.2 The two principal pitfalls which might result in the suggested monetary values of the items failing to approximate to the actual values found if used are that the program will undervalue items possessing benefits independent of their essential amino acid profile, and that it might seriously overvalue items possessing undesirable elements - toxins, etc. Feeding trials would probably be required to indicate any major departures from the monetary values suggested here.

2.6 NUTRITIONAL REQUIREMENTS OF TROUT

2.6.1 The nutrient requirements of trout and other salmonids are reviewed in a number of papers and books. (Halver, 1976; Halver, 1972; National Academy of Sciences, 1973; and others). The nutrient requirement values as used in this program are based largely on Halver, 1972, with amendments based on other authors where relevant.

The diet of the trout must provide the fish with protein, fats, minerals, vitamins and energy, and the known specific requirements of these elements are discussed in the following sections.

2.6.2 Protein is required in substantial quantities in the diet in order to provide amino acids used by the trout in the generation and replacement of tissue. In some instances protein may be supplemented by synthetic amino acids, especially lysine.

Twelve amino acids are generally considered essential in the trout's diet, and are listed along with the accepted percentage requirements in Table 2.6. According to some authors ten amino acids only are essential in the diet, the two acids cystine and tyrosine not being typically essential in themselves but exhibiting a sparing action on methionine and phenylalanine respectively. Amino acid requirements are still poorly understood, and substitution may be possible between other acids. A great deal of work remains to be done also on the variation of amino acid requirements with other factors, e.g. temperature, age of fish, etc. Smith (1976) points out that the amino acid requirements reported in the literature are specific for the set of conditions during the test, while the balance of amino acids in the protein of compound feedstuffs might be such as to change the requirement for any one specific amino acid. Some feeding trials with salmon have indicated a direct relationship between temperature and protein requirements. (Halver, 1980). In the light of our present extent of knowledge, however, the amino acid levels listed in Table 2.6 are considered adequate and were used as the constraints in the linear programming model (Appendix G). An overall protein level of around 40% is generally considered optimal, and a net protein requirement of 42% and a digestible

TABLE 2.6. ESSENTIAL AMINO ACID REQUIREMENTS OF RAINBOW TROUT

(FROM E.I.F.A.C., 1971)

Amino Acid	Requirement as % of Total Protein	Requirement as % of Diet Containing 42% Protein
Lysine	5.0	2.10
Methionine + Cystine	4.0	1.68
Argine	6.0	2.52
Tryptophan	0.5	0.21
Leucine	3.9	1.64
Isoleucine	2.2	0.92
Threonine	2.2	0.92
Histidine	1.8	0.76
Phenylalanine + Tyrosine	5.1	2.14
Valine	3.2	1.34

protein requirement of 35% were assumed.

Two known effects of amino acid imbalance were also taken into consideration. Excess leucine appears to inhibit salmonid growth when the ratio 3:1 leucine:isoleucine is exceeded. High levels of valine do not appear to inhibit growth, but may reduce performance efficiency when included at levels of more than 3% of the diet. (National Academy of Sciences, 1973).

2.6.3 There appears to be a nutritional requirement for some fats and oils in salmonid diets. However, very little is known concerning the requirements for specific fatty acids, although at least one, linolenic acid, is believed to be essential (E.I.F.A.C., 1971), while Sedgwick (1973) includes linoleic and arachidonic acids also. Similarly the fatty acid content of many of the potential feed items being tested is poorly known. Consequently the program directs itself primarily to the evaluation of feed items by virtue of their protein contribution to the diet, and the fat requirement is not specifically allocated to individual fatty acids. The linolenic family ($\omega 3$) fatty acids are believed to be essential for rainbow trout, and the requirement may be met when about 5% fish oil is included in the diet (NAS, 1973). Accordingly a constraint for 2% cod liver oil is included in the program to supplement the oil already present in most of the diets by virtue of the herring meal content. Halver (1980) states that it remains to be seen whether some dietary level of $\omega 6$ fatty acids is essential to the wellbeing of salmonids.

Fats included in salmonid diets serve as energy sources, sparing dietary protein for growth and tissue replacement (Phillips et al, 1955). In excessive amounts, however, fats may result in deposition of body fats in the fish and in infiltration of the livers (Davis, 1953; Sedgwick, 1973).

The fat constraints used in this program are 6% and 15% of the diet (lower and upper limit respectively). This is stated to be about average in modern salmonid diets (E.I.F.A.C., 1971) (see also Appendix A on trout feed compositions), although with the rider that higher fat levels may be acceptable if the diet is well-balanced in other respects. The National Academy of Sciences (1973) suggests that the fat content in commercial trout diets ranges from 6% to 14% and that these levels should be considered minimal and could be increased with advantage provided that fat stability could be guaranteed. Austreng (1979) suggests that up to 16% good quality fat may be included in salmonid diets. Huet (1972) on the other hand states that fat levels should not exceed 8%. In view of the conflicting evidence available, limits of 6% and 15% were considered to be a fair compromise.

2.6.4 A definite requirement for carbohydrates in salmonid diets has yet to be convincingly demonstrated, but they may be used as an energy source, thus sparing proteins and/or fats, when used in small quantities only (E.I.F.A.C., 1971). There is however virtually no storage of carbohydrate in the salmonid body, with the exception of small quantities of glycogen (E.I.F.A.C., 1971). Crude fibres are virtually indigestible by salmonids, and when present in compound diets act as ballast but in other respects are almost inert. The less complex carbohydrates may be very much more digestible however (See Section 2.7 on digestibility of feedstuffs).

The National Academy of Sciences' sub-committee on fish nutrition (NAS, 1973) state that some trout nutritionists have placed maximum digestible carbohydrate in trout rations at 20%, and this figure would appear to be consistent with a number of tested rations. Gross (undated) on the other hand states that the crude fibre should not exceed 10% and should preferably lie between 5% and 6%, and that the upper limit for other carbohydrates should be 30% of which no more than 10% should be digestible to give a total digestible carbohydrate content of around 3-4%. At the other extreme, Chow and Halver (1980) state that rainbow trout have been shown to effectively utilise up to 60% of glucose, sucrose or lactose in the diet. The low levels suggested by Gross would not appear to be generally backed by other authors or by published formulations of commercial trout diets. Part of the discrepancy may be explained by the tests being carried out at different temperatures, high carbohydrate rations fed at cold temperatures causing excessive storage of glycogen in the liver and possibly resulting in the death of the fish (NAS, 1973). Bearing in mind the large number of published diet formulations containing high levels of carbohydrates, the National Academy of Sciences' recommendation of a 20% digestible carbohydrate upper limit is accepted and used in this program for evaluation. A lower limit of 3% was used. Commercial trout pellets generally contain around 20-30% carbohydrate (Appendix A), giving in the region of 5-10% digestible carbohydrate.

2.6.5 A number of vitamins have been demonstrated to be essential to the proper development of trout, and these are summarised in Table 2.7. As with proteins, however, further work on the relationships between requirements and external factors would be desirable.

Fish are apparently able to obtain minerals and essential trace elements both from the diet and from the water in which they live The extent to which they are capable of extracting trace elements from

TABLE 2.7.

AVERAGE VITAMIN REQUIREMENTS OF FARMED SALMONIDS (E.I.F.A.C., 1971)

(NET REQUIREMENTS PER Kg OF DRY DIET)

Vitamin	Net Requirement Per Kg Dry Diet		Recommended Level Per Kg Dry Diet
Vitamin A	?	I.U.	15,000
Vitamin D3	?	I.U.	3,000
Vitamin E	30	mg.	60
Vitamin K3 - Bisulfite	?	mg.	5
Vitamin C	100	mg.	500
Thiamine	6	mg.	15
Riboflavin	20	mg.	30
Niacin	125	mg.	175
Pantothenic Acid	35	mg.	50
Pyridoxine	10	mg.	15
Vitamin B12	10	mcg.	50
Folic Acid	3	mg.	5
Biotin	1.5	mg.	2.5
Inositol	600	mg.	1,000
Choline	300	mg.	2,000

the environment is however poorly known, and it is thus difficult to determine the quantities required in the diet. The following trace elements have been reported to be essential to salmonid nutrition; iron, sodium, calcium, magnesium, potassium, manganese, zinc, copper, cobalt, selenium, chromium, barium, iodine, phosphorus, chlorine, fluorine and bromine. Chinook salmon require between 0.1 and 1.0 mg of iodine/g of dry diet (NAS, 1973). Specific dietary requirements for other minerals have yet to be defined.

Cod liver oil, yeast products and seaweed meals are often added in small and constant quantities to supply vitamins and minerals to the diet. Many moist feed formulations make use instead of a vitamin/binder premix which serves to bind the moist materials, reducing wastage and loss of liquid components in the ponds. A vitamin/binder is included in the programmed formulation at a recommended level of 4% and is assumed adequate to satisfy the mineral and vitamin requirements of the trout.

2.6.6 Energy is a prime dietary requirement, and may be supplied by oils, fats, carbohydrates and proteins. Phillips (1969) suggests a metabolisable energy of crude protein as being 3,900 Cal/Kg, of crude fat 8,000 Cal/Kg and of carbohydrate 8,000 Cal/Kg, and assumes respective digestibilities of 88%, 87% and 40%. Estimates such as these are becoming increasingly refined through the use of respirometer measurements (Smith et al, 1969).

Absolute figures on energy requirements are not well known in fish nutrition (NAS, 1973), but fish receiving minimum levels of 5% digestible fat and 5% digestible carbohydrate should have sufficient to meet their energy requirements without resorting to using the protein faction as a source of metabolisable energy. Good conversion ratios in later stage feeding trials would be considered as demonstrating that this is the case.

2.7 DIGESTIBILITY OF NUTRIENTS

In order to properly evaluate dietary materials such as those listed in Appendices D & E it is necessary to convert the figures for gross nutrient content into figures for digestible nutrients.

Digestibility in fish is most commonly measured by mixing chromium oxide (Cr_2O_3) in the prepared diet and then analysing the faeces. Per cent digestibility is then expressed as:

$$\frac{100 - \%\ CR_2O_3 \text{ in faeces}}{\%\ Cr_2O_3 \text{ in feed}}$$

This is at best an approximation, failing to take into account non-faecal nitrogen (de-aminated amino acids excreted via the gills.) Variations on the theme and attempts to develop alternative methods are described by Smith (1980) and Phillips (1969).

The digestibilities of a number of the materials included in the basal diet formulation have been determined with respect to rainbow trout, and these are included in Appendix F. Reliable measurements of the digestibility of certain of the items were unfortunately not available, and estimates had to be made on the basis of the digestibility of similar materials by rainbow trout or the digestibility of the same material by a similar fish species (e.g. Atlantic salmon, brook trout) where these are known. It must be conceded that such estimates may be misleading, but it was considered that this was the best option in the circumstances. It is to be hoped that current interest in digestibility coefficients will increase our knowledge and reliability in this field in the near future. The National Academy of Sciences (1973) records protein digestion coefficients for a large number of materials by carp and catfish, but the digestion of neither species resembles that of trout closely enough for the figures to be of much relevance here. The corresponding NAS study on the nutritional requirements of coldwater species regrettably fails to include similar records for protein digestion by salmonids.

The digestibility is known to vary between different environmental conditions such as water temperature and salinity (Cho and Slinger, 1979; Lall and Bishop, 1976) but the effect appears to be slight and is not allowed for in the program. Philips and Brockway (1959) assumed fat digestibility of 85% and protein digestibility of 90%, and these assumptions are also used here where more specific figures are not available. Carbohydrates are assumed to be 20% digestible as suggested by E.I.F.A.C. (1973) except where levels of specific relatively simple carbohydrates with a high digestibility such as lactose and sucrose are known to be high. Philips et al (1948) determined the digestibility of carbohydrates by brook trout as follows:

Glucose	99% digestible
Maltose	92% "
Sucrose	73% "
Lactose	60% "
Cooked Starch	57% "
Raw Starch	38% "

Accordingly, carbohydrates are assumed to be 20% digestible except where high levels of the easily digested carbohydrates listed above occur in a product, e.g. lactose in milk products, sucrose in molasses, etc. In other materials, the 20% digestibility is arrived at by counterbalancing the two major carbohydrate factions in most feedstuffs, raw starch and crude fibre, approximately 38% digestible and 0-5% digestible respectively.

The nutrient composition of the materials evaluated, adjusted for digestibility, is recorded in Appendix G.

2.8 SUMMARY OF EVALUATION OF MATERIALS

Materials were evaluated subject to the dietary contributions and constraints specified in Appendix G and at prices prevailing at January 1980. The values thus obtained are all discussed in the relevant sections of the text, and are summarised in a series of tables contained in Appendix H, indicating the value of the item assuming either 90% or 80% digestibility. Sensitivity of each item to relative changes in the price of other major protein competitors (herring meal, white fish meal, and meat and bone meal) are also indicated.

As a further check and/or confirmation of the values thus suggested, an analysis of three of the more promising items - maggots (M. domestica) and earthworms (E. foetida and L. terrestris) - were supplied also to Edward Baker Ltd., Manufacturers of "Omega" trout feeds, who evaluated these three items on their own L.P. package. The values output by this optimisation package are included in Appendix H for comparison purposes.

All the values thus obtained are used and discussed in the appropriate sections of the text and also in the later summary sections, and it would therefore be inappropriate to discuss any of these results here except insofar as has been done to illustrate the valuation methodology used.

Chapter 6 also uses linear programming techniques to optimise (rather than evaluate) a moist diet drawing upon a much reduced list of ingredients in the text. The methodology and the constraints used were however the same, and the same L.P. package (MPOS) was also used. The discussion of the results of this second run is confined to Chapter 6.

The following three chapters consider the potential economic usefulness of selected novel materials under the three main categories of fresh animal materials, single cell proteins and plant materials, and indirect materials for the culture of food organisms.

CHAPTER 3

Use of wet animal materials

3.1 FEED MATERIALS PRESERVATION COSTS

Virtually any means of preserving food materials insurs a cost in addition to the price of the raw material, and a steady supply of fresh raw materials (e.g. fish from a nearby year-round port or offals from a local abattoir) may often be most economically utilised immediately in the state bought without the need for any means of preservation. Such situations with a guaranteed supply of good quality material at stable prices are however comparatively rare, and in many cases the full utilisation of animal materials as they become available depends on some form of preservation in order to ensure a steady supply of usable material. Costs of preserving animal proteins (using fish as an example) by three methods - freezing, meal reduction and ensilage - are considered and compared here prior to the discussion of individual materials.

It must be emphasised that all such costings are liable to a great deal of variation depending upon individual situations/circumstances and the design of the system, especially as regards trade-offs between capital intensive and labour intensive methods. The costings given below must therefore be seen as a guide only to the relative costs of preservation by different means. These costings serve a useful purpose in illustrating the manner in which cost per ton of fish preserved may vary with the scale of operation, in particular the relatively small size of operation of ensilage at which further economies of scale become negligible as the cost of formic acid becomes an increasingly important factor of the total cost.

Cost of preservation of other wet animal materials, e.g. meat offals, is likely to bear a close resemblance to the examples for fish, with the exception that meal preparation is highly dependent on the water content of the material and will therefore be higher for materials such as blood.

3.2 COSTS OF FREEZING

Unlike reduction to meal or to silage, preservation by freezing requires two separate operations; the initial freezing of the material and its continuing cold storage until used. The costs of preservation by freezing therefore depend to a large extent upon the timescale over which the material will be in storage. Storage costs of silage, and even more so of meal, are by contrast a small proportion of the cost incurred in the initial reduction process.

The costs of preserving fish for use in fish feeds are considered for four different sizes of operation and/or intended storage periods. All costs are for January 1980. Estimates from Wathes and Co. refer directly to this period, while these estimates based upon a costed example for 1976 (F.A.O. Technical Paper 162) have been adjusted to January 1980 prices using the index for refrigeration machinery (from "Price Index Numbers for Current Cost Accounting, 1980) with regard to capital machinery costs, and the retail price index for operating costs. It would have been preferable to have found a better method for standardising these costs, but the large number of individual indices relating to specific aspects of the operation and their differing publication periods prevented this. As stated in 3.1, costs are in any case liable to a great deal of variation depending on individual circumstances, and the costs given here are regarded as sufficiently accurate for the intended purpose, i.e. to indicate the manner in which costs vary with the scale of output and the preservation period, and also to suggest the likely level of storage costs when farm-prepared feedstuffs are used as an alternative to dry compound pellets.

System 1. Capacity 50 tons per annum, 1 ton being delivered on a weekly basis and frozen within 24 hours and used over 1 week. Depends on a regular supply of fish throughout the year. Costs are based upon an estimate from T H Wathes & Co.

System 2. Capacity 500 tons per annum, 10 tons being delivered on a weekly basis and frozen within 24 hours and used over 1 week. Depends on a regular supply of fish throughout the year. Costs are based upon an estimate from T H Wathes & Co.

System 3. Capacity 500 tons per annum,50 tons being delivered on a 5 weekly basis and frozen within 24 hours and used over a period of 5 weeks. Permits some flexibility of buying materials in order to avoid short term scarcity, but depends on non-seasonal supply. Costs are based upon those for system 4 but with reduced operating costs to take account of reduced degree of utilisation.

System 4. Capacity 5,000 tons per annum, up to 50 tons being frozen per day but likely to be working at less than full capacity for most of the year. Deliveries on a daily basis throughout the year depending upon availability, and being held in cold store for up to one year or until used. May make maximum use of seasonal fisheries to take advantage of low buying prices. Costs are based upon an example from F.A.O. Technical Paper 162, adjusted for price inflation as previously described, with cold store costs based upon estimates from T H Wathes & Co and Prestcold Northern.

Systems 1, 2 and 3 all take deliveries at intervals of 1 week or more, yet freezing should be completed within 24 hours to maintain quality of fish. There is necessarily therefore a considerable degree of underutilisation of the capital freezing plant which is unavoidable if the plant is to be of sufficient size to process a single delivery within a reasonable time. Contracting for the freezing to be done by a specialist freezing firm might prove to be a cheaper alternative, while there may also be economies to be realised by several farms undertaking freezing on a co-operative basis.

Tables 3.1 and 3.2 summarise the costs of freezing and cold storage by each of the four systems envisaged. There is of course an almost infinite range of combinations of delivery sizes/delivery frequencies/cold storage periods, etc, and it has not therefore proved possible to provide a generalised model for the estimation of the costs involved in preservation by freezing, and the information provided in Tables 3.1 and 3.2 and Graphs 3.1 and 3.2 indicating the relationship between capital cost and capacity for freezing and cold storage purposes is intended to indicate the order of magnitude and the variability of these costs only.

TABLE 3.1 COSTS OF FREEZING

CAPITAL COSTS AND CHARGES	System 1 50 t.p.a.	System 2 500 t.p.a.	System 3 *2 500 t.p.a.	System 4 *2 5,000 t.p.a.
Capital cost of refrigeration plant + accessories where applicable (Belt conveyors, etc.	£5,400	£35,000	£94,000	£94,000
Services (10%)	£540	£3,500	£9,400	£9,400
Power Consumption p.a.	10,000 KwH.	72,700 KwH.	45,900 KwH.	459,000 KwH.
at 2p per KwH	£200	£1,450	£920	£9,200
Depreciation (10%)	£590	£3,850	£10,340	£10,340
Insurance	£120	£770	£2,070	£2,070
Maintenance & repairs (6%)	£360	£2,310	£6,210	£6,210
Total Capital Charges:	£1,170	£6,930	£18,620	£18,620
OPERATING COSTS				
Power Consumption	£200	£1,450	£920	£9,200
Labour at £2.4p per hr. *3	1 man for 450 hrs. £1,080	2 men for 1,200 hrs. £5,760	5 men for 240 hrs. £2,880	5 men for 2,000 hrs.+ 800 hrs. at time and a quarter. £36,000
Supplies - Refrigerant Oil, Packaging, etc.	£50	£300	£300	£2,700
Total Operating Charges	£1,380	£7,750	£4,220	£49,400
Total Annual Charges: Fixed	£1,170	£6,930	£18,620	£18,620
Operating	£1,380	£7,750	£4,220	£49,400
Total	£2,500	£14,480	£22,720	£66,520
Fish Frozen	50 tons	500 tons	500 tons	5,000 tons
cost per ton	£50	£29	£45.5 *1	£13.3

*1 The apparent high cost per ton using this ystem is clearly due to underutilisation of capital intensive plant.

*2 Plant used in two cases is the same, differing only in degree of utilisation.

*3 Hours worked are author's estimates only.

TABLE 3.2 COST OF COLD STORAGE (JAN 1980)

(BASED ON ESTIMATES FROM T.H. WATHES & CO & PRESTCOLD NORTHERN).

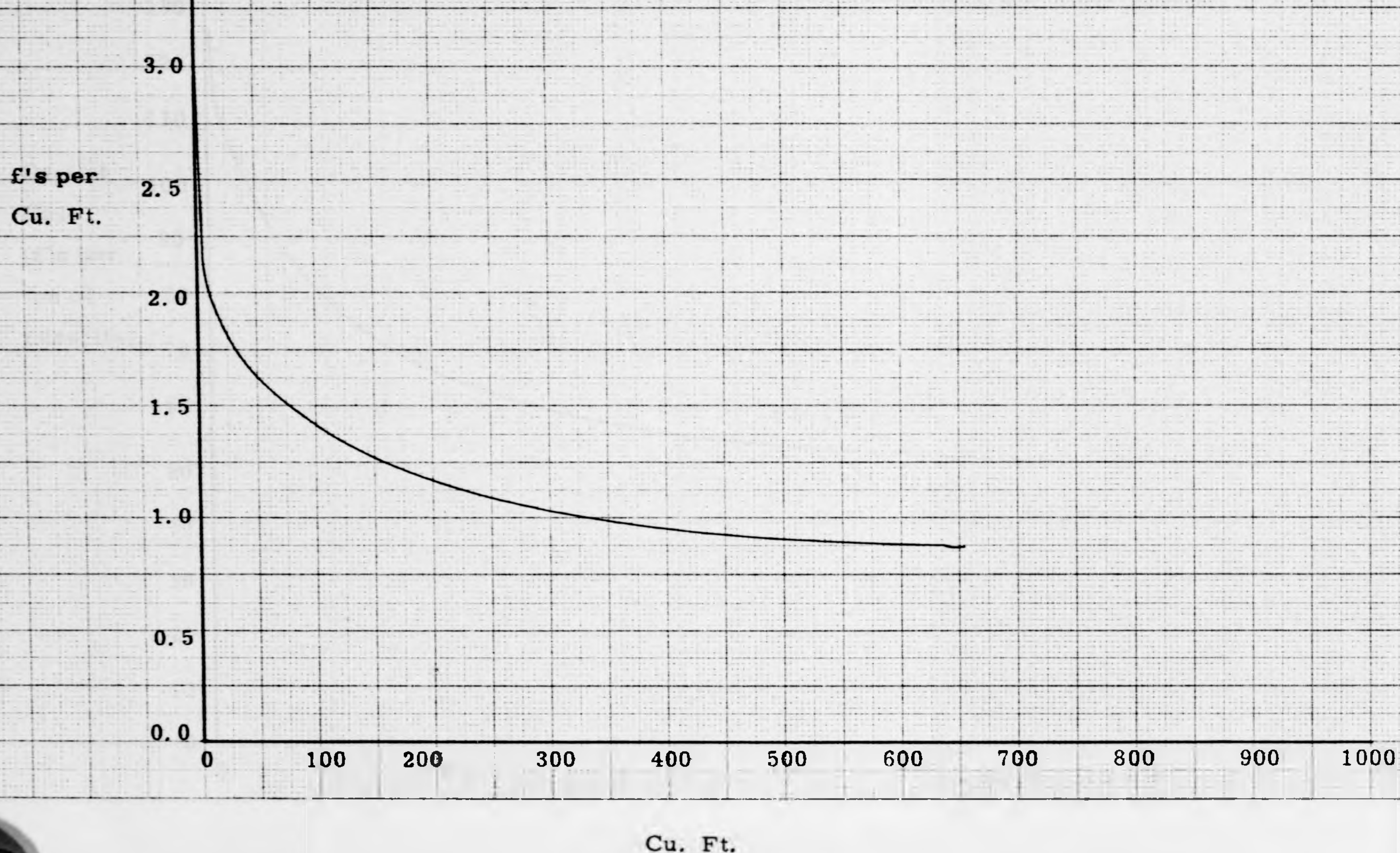
	System 1	System 2	System 3	System 4
Max. Storage time	1 week	1 week	5 weeks	1 year
Av. Storage time	½ week	½ week	2½ weeks	6 months
Capacity required	1 ton	10 tons	50 tons	2,500 tons
(at 10 lbs per cu. ft.)	200 cu.ft.	2,000 cu. ft.	10,000 cu. ft.	500,000 cu. ft.
Cost per cu. ft. of plant (£'s)	5.0	3.5	1.75	0.95
Capital Cost of Store (£'s)	£1,000	£7,000	£17,500	£475,000
Depreciation 10%	£100	£700	£17,500	£47,500
Insurance 4%	£40	£280	£700	£19,000
Maintenance 4%	£40	£280	£700	£19,000
	£180	£1,260	£2,450	£85,500
OPERATING COSTS				
Power (at 2.0 p. per KWH)	20 KwH x 365 =£150	68 x 365 KwH =£500	95 x 365 KwH =£690	500 x 365 KwH =£3,650
Labour *1 (at £2.4 per hr.)	1 man for 50 hrs. =£120	1 man for 500 hrs. =£1,200	1 man for 500 hrs. =£1,200	3 men for 2,000 hrs. =£14,400
Supplies (Oil, Refrigerant, Office Stationery, etc.	£10	£20	£30	£150
Total Annual Charges: Fixed	£180	£1,260	£2,450	£85,500
Operating	£280	£1,720	£1,920	£18,200
Total	£460	£2,980	£4,370	£103,700
Tons stored (P.A.)	£50	£500	£500	£5,000
Cost per ton	£9.2	£6.0	£8.7	£20.7 *2

*2 Note: The apparent high cost of this sytem is due to the very long periods of storage involved, not diseconomies of scale.

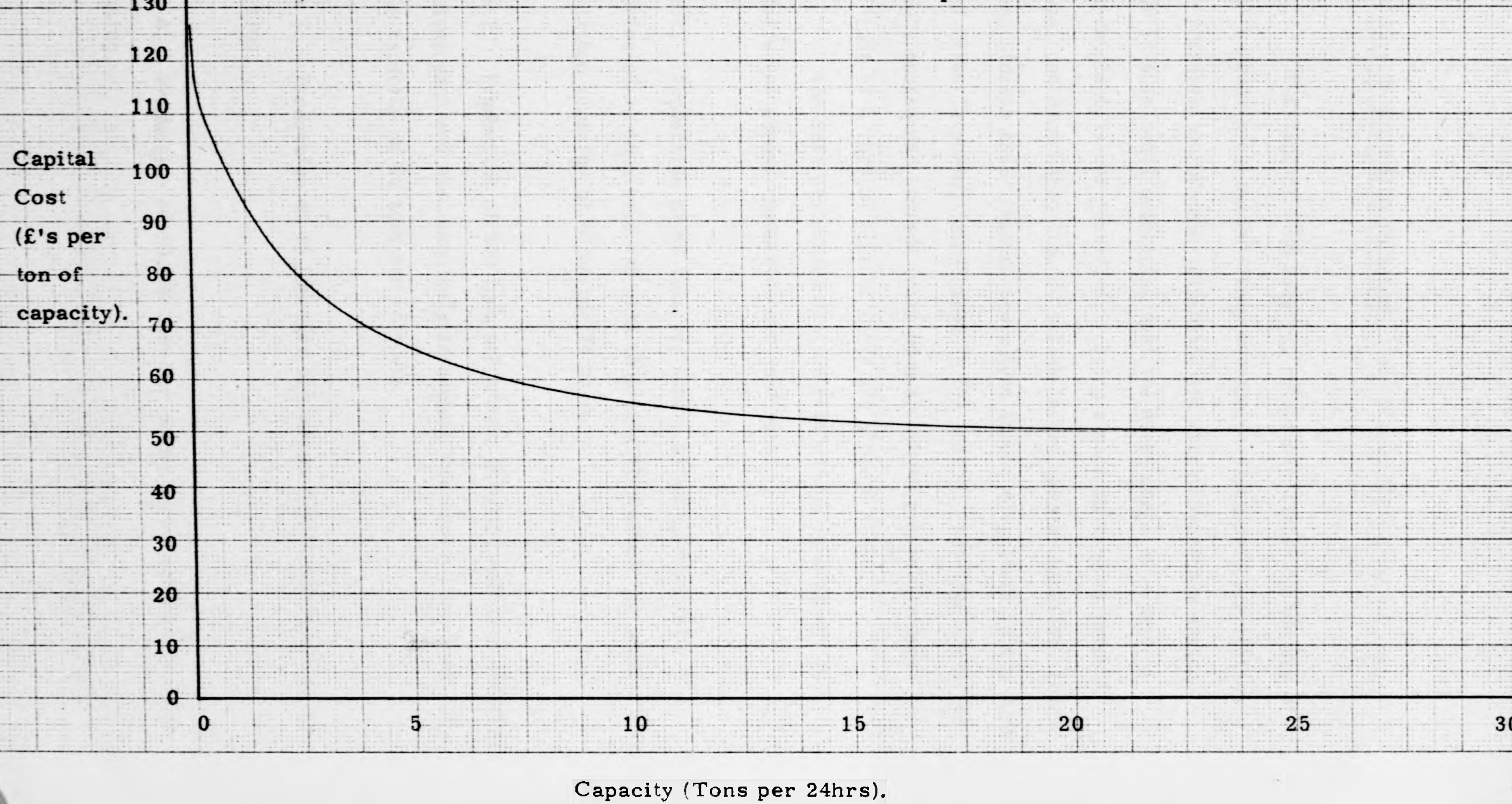
*1 Based on author's estimates only, and assumes full time labour used in other operations on site when not in use here.

Graph 3.1. Relationship between capital cost and capacity of cold strore

(Based on estimates from T. H. Wathes and Co. and Prestcold Northern, 1980).



Graph 3.2. Relationship between capital cost and capacity of freezing plant
(Based on estimate in F. A. O. Fisheries Technical Paper No. 167.).



3.3 COSTS OF REDUCTION TO SILAGE

Ensilage of fish requires relatively little in the way of capital expenditure, and is likely to receive its widest application in the preservation of materials which are either available seasonally or in such small quantities that the development of a meal reduction plant is not justified. Being a much more bulky product than meal and also being liquid, silage incurs greater handling, transport and storage costs than an equivalent amount of protein in the form of meal, thus favouring local usage. The initial ensilage costs far outweight subsequent storage costs however, which are really only significant as a capital cost of space and storage tanks.

The unit production cost of fish silage is examined for four different annual capacities and load rates:

System 1. Production of 50 tons per annum, assuming 5 annual deliveries of 10 tons each and used regularly throughout the year, with maximum capacity of 1 ton per 24 hours.

System 2. Production of 500 tons per annum, assuming weekly deliveries of 10 tons each and used regularly throughout the year, using plant of maximum capacity of 50 tons per 24 hours.

System 3. Production of 10,000 tons per annum, using continuous batch processing.

System 4. Production of 20,000 tons per annum, using continuous batch processing.

Systems 3 and 4 are based on an example costed by Nicholson (1976), updated to January 1980 prices according to appropriate indices from the Department of Industry's "Price Index Numbers for Current Cost Accounting, April 1980" as indicated in the cost tables. Systems 1 and 2 are costed according to similar breakdown units but using costs derived from manufacturers price lists. These costs are summarised in Tables 3.3 and 3.4.

Note that capital depreciation is a minor factor in all but the smallest systems, and that it is largely the cost of materials (e.g. formic acid) that determines the minimum cost. Also in smaller systems, the incorporation of oil extraction plant (possibly necessary in ensilage of oily fish) adds greatly to the total capital cost, but may not be required where the silage is intended for subsequent consumption by other fish, where "fishy" taints to the flesh resulting from the oil content would not be as undesirable as in other farmed animals. Precautions would however require to be taken against the high thiaminase levels of some oily fish, particularly herring, by the addition of thiamine to the diet.

TABLE 3.3 COST OF ENSILAGE (CAPITAL)

			System 3.*1	System 4.*1
	50 tons p.a.	500 tons p.a.	10,000 tons p.a.	20,000 tons p.a.
Capital Cost of Grinder:	£4,000	£4,000	£11,000*2	£23,400
Capacity	5t per hr.	5t per hr.	20t per hr.	20t per hr.
	Eg. Torelli SC 190/V.A.	Eg. Torelli SC 190/V.A.	Eg. Working grinder + conveyor type 250-IT-70.	
Mixer	£1,000	£1,000	£8,200*2	£8,250
Capacity	5t per hr.	5t per hr.	Wolfking mixer type	50 tons per hr.
Type:	Alvan Blanch M45	Alvan Blanch M45	No. 2000	Alvan Blanch M600
Digestion Tanks + stirrers	£2,000	£2,000	£8,200*2	£16,400
Size	1 x 10 ton	1 x 10 ton	2 x 25 ton	4 x 25 ton
Oil Extraction	(£40,000)	(£40,000)	(£70,400)*2	(£140,800)
Equipment				
(If required)			Decanter- Westfalia*2 Contrifuge- Westfalia Boiler.	Type A2-20 Type SA.20-03076
Acid holding tank	£1,500	£1,500	£7,800*2	£11,000
(Size)	2 ton	2 ton	12 ton	20 ton
Storage: 45 gall. drum	£5x50	£5x50	£5x1000*2	£5x2,000
	= £250	= £250	= £5,000	= £10,000
Total	£8,750	£8,750	£40,900	£69,050
(+ oil extraction plant	(48,750)	(48,750)	(111,300)	(209,850)
Depreciation (All at 10 yrs. except	£900	£900	£4,590	£7,905
45 gall. drums at 2 yrs.	(£4,900)	£4,900)	(£11,630)	(£21,985)

TABLE 3.4 FISH SILAGE PRODUCTION COSTS (JAN 1980)

(Figures in Brackets refer to inclusion of oil extraction process costs).

Direct Costs	50t.p.a.	500t.p.a.	10,000t.p.a.	20,000t.p.a.
Labour	£1,000	£2,400	£10,200*3	£20,400
	2 menx210 hr	2xmen 500 hr		
	at 2.4per hr	at 2.4per hr	2 men full time.	4 men full time.
Maintenance (At 79.7p per ton of raw material	£40	£400	7,970*4	15,940
	£40	£400	7,040*5	14,080
Materials (e.g. Formic acid, 85% proof at £340 per ton:	500	5000	100,000	£200,000
Total direct costs	£1,580	£8,200	£125,210	£250,420
Fixed Costs:				
Depreciation	£900	£900	£4,590	£7,905
	(£4,900	(£4,900)	(£11,630)	(21,985)
Insurance 1% of capital	£90 (£490)	£90 (£490)	£410 (£1,110)	£710 (£2,120)
Maintenance 4% of capital	£350 (£1,950)	£350 (£1,950)	£1,640 (£4,450)	£2,860 (£8,500)
Total Fixed Costs	£1,340 (£7,340)	£1,340 (£7,340)	£6,640 (£17,190)	£11,475 (£32,605)
Total Production Cost, excluding cost of ensiled material	£2,920 (£8,920)	£9,540 (£15,540)	£131,850 (£142,400)	£261,895 (£283,025)
Fish Ensiled	50 tons	500 tons	10,000 tons	20,000 tons
Cost per ton	£58.4 (£178.4)	£19.1 (£31.1)	£13.2 (14.2)	£13.1 (£14.2)

*1, 2 and 3: Indices used in updating costs for sytems 3 and 4 explained in Appendix K

3.4 COST OF FISH MEAL PRODUCTION

Fish meal production is a very much more capital intensive process than ensilage, and consequently is only generally considered when raw material is available regularly throughout the year and in substantial quantities. Being a virtually dry product, however, storage and transport are both relatively cheap when compared with frozen fish and fish silage, thus making this material suitable for widespread use throughout the country and in compound feedstuffs and reducing the need to find local outlets.

The unit production costs of fish meal is considered for a single size plant operating at two different levels of capacity, based on a plant designed to process a maximum of 100 tons of fish per 24 hours (to produce approximately 30 tons of meal per 24 hours) costed by J H Merritt in "Assessment to the Production Costs of Fish Protein Hydrolysates", Torry Symposium on fish protein hydrolysates, 1980.

The two levels of capacity considered are:

1. 50% full normal capacity.

2. Full normal capacity.

The costs of fish meal production are summarised in Table 3.5, and indicate clearly that large scales of operation are required to make the process economically competitive with alternative presentation methods.

TABLE 3.5 CAPITAL COSTS OF MEAL PRODUCTION (CAPACITY 100 TONS/24 HRS)

(Jan. 1980)

Plant and Machinery	£700,000
Freight and transport	£ 80,000
Buildings (200m^2)	£ 40,000
Office and Workshops (400m^2)	£ 40,000
Storage for 1200 tons of product	£ 60,000
Miscellaneous	£ 80,000
Total	£1,000,000
Annual Fixed Costs	
Depreciation (5 years)	£200,000
Insurance (2% of capital)	£ 20,000
Maintenance and repairs (6% of capital)	£ 60,000
Management and Supervision	£ 60,000
Total	£340,000
Variable Costs per ton of raw material	
Fuel	£ 8
Electricity	£ 1
Bags	£ 1
Labour	£ 4
Water, Chemicals, etc.	£ 1
Total	£15

Total Production Costs	7,500 tons p.a. (raw material)	15,000 tons p.a. (raw material)
Annual Fixed Costs	£340,000	£340,000
Annual Variable Costs	£112,500	£225,000
Total	£452,500	£565,000
Cost per ton of raw material preserved	£60.3	£37.7

3.5 ANIMAL MATERIALS STUDIED

The following wet materials were considered to merit further study on the basis of those criteria outlined in Section 2.2:

1. Industrial fish and fish offals (fresh and frozen).
2. Shellfish and shellfish offals (including crustaceans).
3. Meat and slaughterhouse offals.
4. Seal meat.

Fish and meat offals both have a history of use in trout culture, both in Britain and abroad, and are available in substantial quantities at fairly well ascertainable prices. Shellfish offals have not to my knowledge been used on any substantial scale in UK trout culture, although mussels (Mytilus) and Nephrops waste have both been used by the White Fish Authority in their pilot scale sole and turbot culture at Hunterston. A number of meals have also been prepared from shellfish and crustaceans and have been used in fish culture elsewhere (e.g. Crab meal in the USA - see Chapter 6) or have been used in experimental trials.

3.6 USE OF INDUSTRIAL FISH AND FISH OFFALS

3.6.1 Virtually all intensive salmonid culture practised in the United Kingdom today relies entirely on the use of compound pelleted feedstuffs, many or all of which contain a sizable proportion of fish meal (frequently between 10% and 30% by weight).

Fish meal is regarded as a high quality protein, being rich in those amino acids, especially lysine and methionine, considered essential to proper stock growth. (See Appendix E). Fish meal is itself easily compensated by other additive mixtures to provide a balanced diet for rainbow trout, the reason that fish meal does not constitute a larger part of the prepared diet being that the same desired result may be more economically achieved using cheaper ingredients to replace part, but not all, of the relatively expensive fish protein. (Fish meal may contain as much as 70% protein, and while trout find such a diet acceptable, part of the protein must be used as an energy source, while the cheaper fats and carbohydrates are quite capable of fulfilling the same role).

3.6.2 As with fish meal, whole wet fish is also easily compensated for nutritional deficiencies (frequently compensation may be altogether unnecessary) and the use of minced wet fish has predominated in Scandinavian (mainly Danish and Norwegian) salmonid culture. This predominance now appears to be weakening dramatically for a variety of factors, as discussed shortly. Shepherd (1973) states that the use of fish or fishery by-products has been attempted on two occasions in the UK to his knowledge, but that both have since been discontinued, one as a result of intervention by the local river authority and the other due to extreme variability in the price of the raw materials. More recently, Marine Harvest have fed fresh fish to Atlantic salmon in sea cages, but this has been discontinued due to the variable quality of the material (MacPhie, 1981).

3.6.2.1 A Danish study on the relative economics of feeding wet fish and dry pellets came out strongly in favour of the former if price and conversion efficiencies only are considered (G J Rasmussen, 1966 and 1969).

Conversion quotients for the dry feed ranged between 1.54 and 2.54, and for the marine fish (mainly herring, whiting and sand-eels) between 3.70 and 5.34, with average values over the whole period of 1.79 and 4.42 respectively. The growth rates were variable, being sometimes higher for the one and sometimes the other feed, Rasmussen suggesting that this is primarily determined by the ability of the operator to adapt the feeding routine to the requirements of the fish. The paper concludes with the statement that "if secondary advantages are not taken into consideration it can be calculated that in the present experiments, the average price of dry feed could have been 2.4 to 2.9 times the price of wet food to be in a competitive position with the traditional wet food used in Danish trout culture. If calculated on the total the price of the dry feed could have been 2.6 times the price of the wet food". He points out however the inherent difficulty of comparing the two on a strictly economic basis, such factors as security of supply and ease of operation being of real but uncertain value.

Certainly many Danish trout farmers considered the practice of feeding wet fish worthwhile, for this method continued to predominate in the industry until strict new Danish pollution laws curtailed it. Trash fish are still widely used in marine cage culture of rainbow trout with satisfactory results.

Trout farming in Denmark has developed almost entirely in a relatively small area (Jutland) with large quantities of industrial fish landed and available locally. In Norway, fish farming occurs over a much wider area, with the result that not all farms are so readily accessible to the fishery landings as are those in Denmark. Fresh fish is still used extensively as a feed in Norwegian marine cage culture of salmonids, but in fresh water this has largely been superseded by dry pellets for the majority of fish, with wet diets remaining in use sometimes for conditioning broodstock. (Edwards,1978).

Edwards states that in Norway, from a simple economic comparison between wet and dry feeds based only on the relative price and conversion efficiencies, dry feeds usually work out cheaper per unit weight of fish produced, this being the converse of Rasmussen's conclusions for Danish culture. (It is noted however that the advantage may lie with trash fish in parts of the North of Norway where fresh fish is landed locally, trout pellets being produced in the South and therefore incurring considerable transport costs).

Edwards' conclusions concerning Norwegian fish farms do not seem to be the experience of Danish farms or of certain isolated instances in Britain where the use of fresh fish has been tried. This may be due to either a higher delivered price for industrial fish in Norway (including transport charges) or to a poorer conversion efficiency. Edwards suggests average conversion ratios of around 6-8:1 for fresh fish and 2.1 for dry feeds, compared with Rasmussen's findings of 4.42 and 1.79 respectively. Rasmussen's figures are, as he admits, rather lower than is generally found in commercial practice, but since this is the case for both figures this does not necessarily affect the relative values.

Any consideration of the relative economics of wet and dry feeds should bear in mind also the extra costs of handling and storing fresh or frozen fish. Furthermore the supply and quality of fresh industrial fish is more variable than that of compound feeds, and the material is less easily incorporated in automatic feeding systems (Section 1.3.1.4). Against this is claimed a superior taste and quality of product when fed wet fish and an apparent preference of trout and salmon for a wet diet. This latter is said to be especially pronounced at the time of transference of smolting salmonids to sea water, but may equally be true at the time of first feeding.

Edwards states that there is currently a trend in Norway against the feeding of fresh fish and towards the use of dry feeds, and that he expects this trend to continue as artificial feeds become more refined.

3.6.2.2 Wet fish has never been widely used in aquaculture in the UK, although it has been tried on occasion, in some cases with fairly encouraging results.

Shepherd (1973) cites two examples where trash fish has been used. The first, Wansford trout farm, used herrings and sprats (then obtained at £20 per ton) and achieved conversion ratios of around 4:1, giving a feed cost per unit weight of trout produced substantially lower than that resulting from the use of dry feeds. However, this practice was stopped by the local water authority on grounds of pollution.

The other example cited, Howietoun and Northern Fisheries at Loch Strom, used fish offals, then available at £6 per ton, to produce trout at £42 per ton of liveweight gain with a conversion of 7:1, compared with £165-£220 per ton of liveweight gain using conventional pelleted feeds (then costing £110 per ton and giving a conversion ratio of 1.5-2:1). Such a saving however fails to take into account the extra costs associated with the wet fish offal diet (handling, storage, etc), and the practice appears to have been halted when the price of offal increased. (The trial seems to have been discontinued when the price rose to £20 per ton some time prior to 1973).

Shepherd further compares the cost effectiveness of three diets for plaice - Queen offals, reclaimed cod flesh and trout pellets, and states that in 1973 the feed cost per ton liveweight gain was £617.6, £518-574, and £188-298 respectively, a clear advantage pertaining to the standard trout pellets. However, both wet diets were expensive relative to normal industrial fish prices (Queen offals £95 per ton, reclaimed cod flesh £140 per ton, trout pellets £157 per ton) (1973 prices) and the White Fish Authority's Ardtoe production unit has used wet fish diets in their turbot cage culture more recently.

A great deal of variability has therefore clearly been experienced in economic comparisons of wet and dry diets, and it is probably therefore necessary to examine each case on its own merits before any firm conclusions can be drawn.

3.6.3 Table 3.6 indicates the wholesale prices and landings of a selection of the lower-priced fish species landed at Scottish ports on a monthly basis during 1978.

Of the wide variety of species available, only Norway Pout, Sprats, Sand-eels and Blue Whiting are available regularly and in quantity at prices of £50 per metric ton or less. Mackerel approach this low price on occasion, and are available in extremely large quantities, while offals of a number of the higher-priced table fish (cod, haddock, etc) may also be available in this price range, along with poor quality fish (small whiting, small saithe, etc) and spoiled catches. A number of the abovementioned species could be obtained during 1978 for a price of £30 per ton or less (Norway Pout,

TABLE 3.6

WHOLESALE PRICES AND LANDINGS OF SELECTED FISH SPECIES LANDED IN SCOTLAND BY BRITISH AND FOREIGN VESSELS (1978)

	January		February		March	
Species	M/T	£ per M/T	M/T	£ per M/T	M/T	£ per M/T
Saithe	995.4	341	1784.1	271	1700.6	256
Dogfish-Spur	737.0	216	424.8	255	759.6	271
Dogfish-Spotted	0.1	80	0.3	283	0.1	540
Flounders	1.8	159	9.5	107	20.4	81
Gurnards	4.7	137	36.8	60	28.0	73
Norway Pout	1079.6	35	1325.8	33	468.4	31
Sand-Eels	-	-	-	-	178.5	28
Herring	3009.0	314	2184.8	334	2253.6	332
Sprats	9358.0	57	11661.1	50	2325.9	57
Mackerel	0.2	585	1.0	167	6.2	230
Horse Mackerel	-	-	-	-	-	-
Blue Whiting	-	-	-	-	0.1	220

TABLE 3.6 (Continued)

WHOLESALE PRICES AND LANDINGS OF SELECTED FISH SPECIES LANDED IN SCOTLAND BY BRITISH AND FOREIGN VESSELS (1978)

	April		May		June	
Species	M/T	£ per M/T	M/T	£ per M/T	M/T	£ per M/T
Saithe	1103.4	298	2319.1	246	1652.9	260
Dogfish-Spur	706.1	241	1276.5	136	659.9	214
Dogfish-Spotted	-	-	0.1	140	1.5	256
Flounders	10.6	89	1.3	113	0.3	127
Gurnards	12.4	156	8.7	129	5.1	150
Norway Pout	0.2	185	4.2	41	327.0	37
Sand-Eels	2496.0	28	6130.0	28	4924.1	30
Herring	562.1	496	959.5	421	1764.7	587
Sprats	8.8	55	-	-	641.2	48
Mackerel	2.3	368	42.4	196	313.8	174
Horse Mackerel	-	-	-	-	-	-
Blue Whiting	1311.5	39	1330.8	46	-	-

TABLE 3.6 (Continued)

WHOLESALE PRICES AND LANDINGS OF SELECTED FISH SPECIES LANDED IN SCOTLAND BY BRITISH AND FOREIGN VESSELS (1978)

	July		August		September	
Species	M/T	£ per M/T	M/T	£ per M/T	M/T	£ per M/T
Saithe	1002.4	281	2246.4	225	2702.5	238
Dogfish-Spur	625.4	177	160.8	221	148.3	279
Dogfish-Spotted	0.8	114	-	-	0.2	235
Flounders	0.2	200	8.4	157	5.5	153
Gurnards	9.1	161	7.8	131	5.9	142
Norway Pout	73.0	29	0.1	320*	0.1	980*
Sand-Eels	3888.5	29	4921.5	30	4271.8	29
Herring	862.4	603	598.1	607	581.4	417
Sprats	1154.3	45	-	-	30.9	18
Mackerel	1027.2	97	26567.7	86	51252.1	93
Horse Mackerel	-	-	0.2	35	0.7	89
Blue Whiting	-	-	91.6	43	-	-

*Very small quantities involved may be responsible for significant price errors.

TABLE 3.6 (Continued)

WHOLESALE PRICES AND LANDINGS OF SELECTED FISH SPECIES LANDED IN SCOTLAND BY BRITISH AND FOREIGN VESSELS (1978)

	October		November		December	
Species	M/T	£ per M/T	M/T	£ per M/T	M/T	£ per M/T
Saithe	1116.4	291	547.0	418	533.7	387
Dogfish-Spur	220.1	263	821.3	267	1233.2	229
Dogfish-Spotted	0.1	80	11.0	179	14.5	109
Flounders	0.1	80	0.1	380	1.1	152
Gurnards	4.4	183	5.6	147	13.6	100
Norway Pout	1106.7	29	1424.1	30	634.1	27
Sand-Eels	1244.5	27	-	-	-	-
Herring	656.3	377	652.4	407	281.0	357
Sprats	1150.8	57	11699.4	50	7603.5	48
Mackerel	28178.6	88	338.7	51	178.3	70
Horse Mackerel	7.8	72	5.3	61	0.1	30
Blue Whiting	0.1	110	-	-	-	-

October to March; Sprats, August to September; Sand-eels, March to October). It appears likely that at the present time (April 1980) industrial fish species (Sand-eels, Sprats, Blue Whiting) could be supplied to a user on a contract basis for around £30 per ton (to be collected from port of landing) provided that substantial quantities (e.g. several hundred tons) could be landed at the one time (MacSween, 1980). The delivery of such large quantities at the one time would however necessitate some form of preservation, in this case freezing and cold storage since it is intended the fish be fed as a whole diet (ensilage might otherwise be used were the fish to be fed as a compound moist ration). The very high costs of freezing (Section 3.2) might make it more economically attractive to purchase fish on landing on a regular (e.g. bi-weekly) basis at the going market rate. In these circumstances, the indications are that the average price paid per ton would be likely to be in the region of £50 (April 1980) although there is no security of supply and the trout farmer would necessarily require to make contingency arrangements in case of scarcity (e.g. storage of a reserve supply of frozen fish or a return to dry compound feeds as required).

White fish offals are widely available at fishing ports, but often in quantities too small to justify their collection and delivery. Where available in substantial quantities on a regular basis it is suggested that white fish offals could be obtained for around £40 per ton (Davidson, 1980). All the above materials are subject to marked fluctuations in price and supply. A number of operators are prepared to supply frozen fish only at a cost of around £125-150 per ton, with additional cold store charges in the region of £1 per ton per week. (Mixed Capelin, Sand-eels, Pout; £125 per ton (Joint Trawlers Ltd., Sweden). Blue Whiting, £144 per ton (£40 per ton fresh for irregular bulk delivery) (Boyd Line Ltd., Hull). Sprats, circa £125 per ton. (1980 prices). Fish stored at -20^{0}F have remained usable for periods of up to a year, enabling a single annual delivery to cold store (although more frequent deliveries are naturally desirable, improving the quality of the product and reducing the cold storage capacity required).

3.6.4 The protein content of most industrial fish species varies between 65% and 75% on a dry weight basis, depending on species, state of maturity, and season (See Table 3.7). Further information on this may be found in Torry Advisory Note No. 38, "The Composition of Fish" (J Murray & J R Burt) obtainable from the Torry Research Station, Aberdeen. Amino acid profiles are available for only selected fish species landed in Britain but where not available are expected to resemble those of herring meal (oily fish species) and white fish meal (white fish species). (See Appendix E).

Relatively few feeding trials have been conducted in the UK to determine conversion efficiencies achieved, and such reports as exist vary markedly. Shepherd (1973) states that Wansford trout farm, using herrings and sprats, recorded conversion ratios of around 4:1, and that Howietoun and Northern Fisheries at Loch Strom, using fish offals, found conversion ratios of around 7:1. In recent years Marine Harvest have used wet fish as feeds on Atlantic Salmon farms, and report that initially conversion ratios were similar to those of pelleted foods (around 2.5:1) but that these remarkably good results deteriorated rapidly thereafter (MacPhie, 1980). This would appear to indicate some dietary deficiency when fed over long periods. The fish used were whiting, small haddock, dogfish and blue whiting.

TABLE 3.7 COMPOSITION OF SELECTED FISH SPECIES

(AFTER MURRAY AND BURT, UNDATED)

Species	% Water	% Fat	% Protein
Blue Whiting (Micromesistuis poutassou)	79.80	1.9-3.0	13.8-15.9
Herring (Clupea harengus)	57-79	0.8-24.9*	14-18
Norway Pout (Trisopterus eomarkii)	73-77	4.2-5.1	16.0
Saithe (Pollachius virens)	81	0.3-0.6	16.4-20.3
Sand-Eel (Ammodytes sp.)	73	6.8	17.8
Sprat (Spraltus sprattus)	70-81	3.8-14.1	14.1-15.3

* Varies with season

Such deterioration in conversion figures has not been reported by other observers using fish.

Industrial fish have been tested at Lowestoft by the Ministry of Agriculture, Fisheries and Food,as diets for both brown trout and rainbow trout. Growth was apparently significantly better when using sprats than when using commerical pellets, and conversion efficiencies of between 2 and 3 were recorded (Purdom, 1978). Blue whiting appeared to be inferior as a feed, but quantitative results for this species are not available (Purdom, 1980).

The use of wet fish as a feedstuff has been much more extensively studied abroad, particularly in Denmark and Norway. (Rasmussen (1969) reported an average food conversion efficiency of 4.4:1 using marine industrial fish, although he goes on to state that this is rather low for commercial practice. Hickling (1974) suggests a conversion ratio of around 6:1 for marine industrial fish, while Huet (1970) suggests a figure as high as 6-8:1.

The very wide variations in recorded conversions make evaluation of mixed industrial fish as a feedstuff rather uncertain. However, the bulk of commercial practice in Scandinavia would appear to indicate that a conversion ratio in the region of 6:1 may be expected, and it is possible that Huet's higher figures result from the use of stale fish (since he states the conversion ratio to be dependent upon the quality and freshness of the material). It is nonetheless evident that in some circumstances conversion ratios a great deal better than this may be achieved.

When used for long periods, herring have been found to produce dietary disorders resulting from a high thiaminase content, which may be countered by adding thiamine or by limiting the amount of herring used in the diet.

3.6.5 Since different farms will find themselves in different circumstances with regard to access to a regular supply of fresh industrial fish, it it not possible here to provide a single estimate of the cost of using a whole fish diet. Instead a number of hypothetical examples with differing access to supplies are costed and compared with a similar production of trout fed on a dry compound diet.

All the examples are based on a unit producing 100 tons of trout per annum, and assume a similar growth rate between industrial fish diets and compound pellets. (Note, however, that some reports (Section 3.6.4) suggest a faster growth rate for fish fed on wet fish diets although this has not been widely demonstrated). It is further assumed that conversion ratios are 6:1, and that 5% by weight of vitamin/binder (at £500 per ton) is added to the minced fish to reduce wastage and to supply essential vitamins.

The examples costed are as follows:

1. Using fresh fish, delivered daily at £50 per ton + transport.
2. Using fresh fish, delivered weekly at £50 per ton + transport then frozen on site prior to use.
3. Using fresh fish, delivered monthly at £50 per ton + transport then frozen on site prior to use.
4. Using frozen fish, delivered twice weekly from commercial cold store at £125 per ton + transport + storage charges.

Only those costs incurred over the use of dry diets (e.g. labour of mincing/mixing; transport of extra bulk, etc) are included as being a part of the cost of feeding. Other costs, e.g. farm overheads, etc, are assumed to be the same for both dry and wet diets and are not therefore included.

3.6.5.1 COST OF FEEDING USING WET FISH DELIVERED DAILY (JAN 1980)

Cost of Fresh Fish	£50 per ton	(Pellets £290)
Cost of Transport	£12.50 per ton*1	(Pellets £12.50)
Cost of Binder (5% by weight)	£25	-
Cost of Mixing	£1.50 (See Chapter 7)	-
Cost of extra labour increased weight of food to be distributed.		
Assume 1 hr. per day at £2.4 per hr.	£1.50	-
	£92.50	£302.50
Conversion Ratio	6:1	2:1
Cost to produce 100 tons of trout per annum:	£55,500	£60,500

*1 Assumes transport from depot within 50-100 miles radius. The price given is of course an approximate estimate only, and is taken as an average figure for delivery charges for a number of feedstuff materials. Note that haulage contractors often charge per mile per ton, whereas firms may deliver their own product and often impose a standard charge per ton provided that the destination is within a specified distance range.

3.6.5.2 COST OF FEEDING USING WET FISH DELIVERED WEEKLY THEN FROZEN PRIOR TO USE (JAN 1980)

Cost of Fresh Fish	£50 per ton
Cost of Transport	£12.50 per ton
Cost of Freezing on Site	£29 (See Section 4.1)
Cost of Cold Store	£6.0 (See Section 4.1)
Cost of Binder (5% by weight)	£25
Cost of mincing/grinding	£2.50 (See Section 7)
Cost of extra labour	
(1 hr. per day at £2.40 per hr.)	£1.50
	£125
Conversion Ratio	6:1
Cost to produce 100 tons of trout p.a.	£75,000

3.6.5.3 COST OF FEEDING USING WET FISH DELIVERED MONTHLY THEN FROZEN PRIOR TO USE (JAN 1980)

Cost of Fresh Fish	£50 per ton
Cost of Transport	£12.50 per ton
Cost of freezing on site	£45.5 (Section 4.1)
Cost of cold store	£8.7 (Section 4.1)
Cost of binder (5% by weight)	£25
Cost of mincing/grinding	£2.50 (Chapter 7)
Cost of extra labour	
(1 hr. per day at £2.40 per hr.)	£1.50
	£145.7
Conversion Ratio	6:1
Cost to produce 100 tons of trout p.a.	£87,420

3.6.5.4 COST OF FEEDING USING FROZEN FISH DELIVERED TWICE WEEKLY (JAN 1980)

Cost of Frozen Fish	£125 per ton*1
Cost of Transport	£20 per ton*2
Cost of binder	£25
Cost of mincing/grinding	£2.50
Cost of extra labour	
(1 hr. per day at £2.40 per hr.)	£1.50
	£174
Conversion Ratio	6:1
Cost to produce 100 tons of trout p.a.	£104,400

*1 If bought on a contract basis, it might also be necessary to pay for the storage charges while held at the commercial cold store. (Commercial charges around £5 per ton per week - Boyd Line Ltd., Personal Communication).

*2 For shorter delivery distances, refrigerated transport would not be required and this charge might be considerably reduced.

3.6.5.5 For a number of fish farms it might be the case that fresh fish are available on an intermittent basis (either regularly for a part of the year only or irregularly throughout the entire year). In such circumstances it would be feasible to feed fresh fish when available and to use frozen fish as a standby. The cost of such a system would be intermediate between system 1 (Section 3.6.5.3) and system 4 (Section 3.6.5.4) in cost, in a manner directly proportional to the proportions of fresh and frozen fish used, i.e. if 300 tons of frozen fish was used and 300 tons of fresh fish, the total feed cost per annum would be in the region of $\frac{55,500 + 104,400}{2}$ = £79,950.

3.6.6 Aside from the obvious dependence upon the prevailing cost of fish, the use of wet fish diets is extremely sensitive to the expected conversion ratios. At a conversion of 6:1, only example 1 of the examples costed would indicate any economic benefits to be gained using a wet fish diet, while examples 2-4 would all cost substantially more than a dry compound pellet. However, as pointed out in Section 3.6.4, conversion ratios reported in practice have varied from around 2.5:1 to 9:1, and such variations naturally have a very profound affect on the economies of use of a wet fish diet.

In addition, the inclusion of 5% by weight of a commercial vitamin/binder mix adds greatly to the cost of a wet fish diet. While Shepherd (1973) states that such binders may improve conversion efficiencies by reducing wastage, it is not known that they do so to an extent which is cost effective. Nonetheless it is considered desirable that such a binder should be used, reducing pollution in the ponds and improving the effluent. Should whole fish (e.g. small sprats, sand-eels, etc) be fed to large trout however without prior mincing, a binding agent would not be required, although other measures would be

TABLE 3.8 COST OF FEEDING INDUSTRIAL FISH (JAN 1980)

(£'s TO PRODUCE 100 TONS TROUT P.A.)

Example	1. Fresh Fish	2. Fresh Fish delivered weekly, frozen prior to use	3. Fresh Fish delivered monthly, frozen prior to use	4. Frozen Fish
Conversion 7:1	64,750	87,500	101,990	121,800
Conversion 6:1	55,500	75,000	87,420	104,400
Conversion 5:1	42,250	62,500	72,850	87,000
Conversion 4:1	37,180	50,000	58,280	69,630
Conversion 6:1				
Binder omitted	40,500	60,000	72,420	89,400
Pellets Conversion 2:1	————	60,500	————	————

desirable to ensure that the trout were receiving adequate quantities of vitamins and essential elements.

Table 3.8 illustrates expected feeding costs using fresh and frozen fish at different conversions and with and without added vitamin/binders.

3.6.7 It would seem that fresh fish can provide an economic alternative to compound pellets where a guaranteed supply is available the whole year round. Should the supply be at all irregular, frozen fish would be required to make up the shortfall, adding to the cost to such an extent as to make the use of a wet fish diet uneconomic unless conversion ratios of rather less than 6:1 were to be achieved (Table 3.8).

All those trout and salmon farms cited which have in the past used wet fish diets (Wansford trout farm; Howietoun and Northern Fisheries Ltd; Marine Harvest Ltd) have since discontinued use of this material. Marine Harvest found very good conversion ratios initially on their salmon units, but these declined thereafter. The use of wet foods was halted in this instance on the grounds of the inconsistent quality of the material and the high capital and labour costs involved in its use. A number of other sea-based salmon and trout units have expressed an interest in wet feeds, the two most common grounds for rejection being the lack of a guaranteed supply and the high costs of freezing and cold storage (unnecessary where regular supplies of fresh fish are available).

The use of industrial fish species would appear to be more promising when used in conjection with cheaper protein materials and compounded as moist pellets, as discussed in Chapter 6.

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The use of industrial fish species would appear to be more promising when used in conjection with cheaper protein materials and compounded as moist pellets, as discussed in Chapter 6.

The use of wet materials raises pollution loads in the effluent and this has recently led to the use of fresh fish being severely curtailed in Denmark. Pollution of the effluent was also responsible, according to Shepherd (1973), for discontinuance of wet diet experiements at Wansford trout farm, and it remains to be seen what the general attitude might be from UK water authorities and whether extensive settling tanks/treatment systems would be required.

It might be expected that the use of fresh fish would increase the risk of transmission of pathogens from the feed to the trout, but little evidence of this appears to be on record. It is also likely that the use of wet fish diets might well affect consumer acceptance of the trout, although the manner in which it would be affected is less certain. Ghittino (1979) suggests that organoleptic characteristics are adversely affected by the use of wet diets. Nonetheless, personal experience would tend to suggest that farmed trout fed on dry pellets are also prone to develop a "hatchery" taste and the issue has not yet been resolved.

3.7 USE OF SHELLFISH AND SHELLFISH OFFALS

3.7.1 A number of shellfish species provide excellent high quality protein feeds for carnivorous fish species, including trout. Many shellfish are themselves highly valued as human foods, such that few are available at a price that might permit their use as animal feedstuffs. Only two shellfish types are available in the UK at a price that might permit such use - cockles and mussels. Cockles, while often relatively cheap (in the region of £50 per ton) are rarely available in any significant quantities, especially in Scotland, and accordingly are not considered further here.

3.7.1.1 Mussels (Mytilus edulis) are common all around the coast and are landed in very large quantities. The price varies according to season and quality (in this case mainly size) and is currently (Jan 1980) in the region of £40 to £50 per ton. Furthermore, mussels are becoming increasingly the subject of commercial aquaculture on the Atlantic seaboard of Europe and to a lesser extent in Britain. This suggests the possibility that sub-standard stock might conceivably be used in animal feedstuffs.

3.7.1.2 High quality mussels comprise about 50% shell and 50% flesh (wet weight) of which some 18-28% is dry matter. Despite the low meat content the meat itself is of high quality, containing between 50% protein (as measured by the author) and 63% protein (Grave, Schultz and Thielen, 1979), and between 10% and 20% fats and oils. Amino acid analyses are unfortunately not available.

3.7.1.3 Mussels are enthusiastically accepted by a great number of fish species, including rainbow trout, and may have some potential as an attractant additive to pelleted feeds to encourage difficult cultured fish species to eat. The White Fish Authority at Hunterston has used mussels, shucked by hand, to rear Dover sole and plaice, and report good growth rates with conversion in the region of 5:1. (Thain and Urch, 1973). Mussels have also been used by the W.F.A. in moist pelleted feeds for Dover sole, again with good results. It is stated that the advantage of using shellfish in the diets is that it contains natural attractants which encourage a feeding response and assist in weaning fish from a live to a moist pelleted diet (White Fish

Authority, 1979).

Mussels have also been used in rainbow trout diets with encouraging results. Grave, Shultz and Thielen (1979) fed rainbow trout on an exclusive diet of mussels for a period of several months. The trout were fed on mussel flesh at levels of 2%, 4% and 6-8% of the weight of the fish daily, the third group (6-8%) being fed to excess at this level, at temperatures increasing from 7^{o}C at the start of the experiment to around 15^{o}C later. The results showed that the trout grew better on the 4% and 6-8% mussel diet than they did on a commercial pelleted diet at the lower temperatures, despite receiving significantly more food (on a dry weight basis) on the pelleted diet. The conversion ratio appears to have been in the region of 4-5:1 for the mussel flesh (wet weight to wet weight), indicating a conversion ratio for whole mussels to trout flesh of around 8-10:1, assuming 50% of the weight of mussels to be shell. Mussels were also found to improve trout growth when fed as an occasional addition to a pelleted diet compared with trout fed on pellets alone. Small scale feeding trials conducted by the author also demonstrated that mussel flesh was enthusiastically accepted by fingerling trout, producing a conversion ratio of around 6:1, and could be fed for long periods without apparent detrimental effects on the health of the fish, although no internal investigations were made.

3.7.1.4 For mussels to compete effectively with pelleted diets, whole mussels would be required at a price of well below £50 per ton to allow sufficient margin to pay for shucking the mussels and the extra labour involved in feeding. While mussels landed for human consumption exceed this maximum price, it is nonetheless conceivable that sub-standard mussels could be made available at sufficiently low cost. Three potential sources of such sub-standard mussels occur:

1. Shucked mussels rejected during processing at mussel-bottling plants. Large quantities of such mussels may be rejected on account of colour or size. However, mussel processing is carried out at present only on a very small scale in the UK, and quantities produced here in this way are negligible.
2. Sub-standard mussels from commercial mussel culture units could be used. During thinning of the mussel beds (or rafts, ropes or nets) smaller mussels may be removed to allow the remaining stock more room to grow. The thinned mussels may be either re-seeded in other areas or may be rejected. However, smaller mussels such as these frequently exhibit a smaller ratio of flesh to shell than the larger mussels - often in the region of only 15-20% flesh (wet weight) - greatly reducing their feed value.
3. Wild mussels could potentially be harvested from areas where commercial quality mussels for human consumption are not present. Areas such as Morecambe Bay contain very extensive beds of such mussels that fail to reach marketable size on account of annual storms which destroy most of the beds and restrict the seed to less than one season's growth.

3.7.1.5 While mussel cultivation remains a minor industry in the UK, a great deal of potential exists and productivity may reach exceptionally high levels - up to 150 tons of mussel flesh per acre exceed this maximum price, it is nonetheless conceivable that sub-standard mussels could be made available at sufficiently low cost. Three potential sources of such sub-standard mussels occur:

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3.7.1.5 While mussel cultivation remains a minor industry in the UK, a great deal of potential exists and productivity may reach exceptionally high levels - up to 150 tons of mussel flesh per acre per annum (Mason, 1972). McAnuff (1979) states that the prospect of reducing mussels to meal for use in animal feestuffs is being examined commercially in Ireland, although I have been unable to trace this, while at least one Scottish mussel dredger has also been investigating the possibility of feeding mussels to fish in sea cages (Moscati, 1980). The general opinion among growers at the moment however appears to be that the price attainable for mussels as a feed material would not justify their cost of production for this purpose, and that wild-caught mussels offer better prospects.

In feeding mussels to fish, it would be necessary to remove the shell. Mechanical methods of achieving this, developed for the human market, would add greatly to the cost of the flesh. However, for aquacultural purposes, it would not be necessary that the flesh be removed whole, and a very much cheaper crushing and separating system could probably be devised. Alternatively, Burt (1980) suggests that mussels could be extracted from the shell by ensiling the flesh, although sulphuric acid would be required rather than one of the organic acids used in preparing fish silage by virtue of the high costs resulting from the neutralisation of much of the added acid by the carbonate of the shells.

In conclusion, while mussels are not at present available at a price that makes them attractive to trout culture, the proven high quality of the flesh in promoting growth indicates that potential uses exist for this material should the culture industry develop in such a way as to make available sub-standard mussels at low cost.

3.7.2 Crab and shrimp meals, prepared from cannery and other processing wastes, have been used in fish feed preparations in the USA on occasion, notably in the preparation of Oregon Moist Pellets (Crawford et al, 1973; see also Section 6.1). These materials are not generally available in significant quantities in the UK and are not therefore processed into meal usually. Locally available shellfish offals have however been used by the White Fish Authority in their moist diet formulations, both queen offals and Nephrops wastes being used. These materials are not available in large quantities and in the case of the latter supply little in the way of nutritive value to the fish, being composed largely of the chitinous shell, while queen offals consist of the viscera with or without the shell. Nonetheless, the addition of these offals appears to improve the palatability of the diet to turbot and Dover sole.

In view of the general attractive nature of many shellfish and crustaceans in trout diets, it is certainly worthwhile making use of such materials where they are freely available and may be incorporated in a farm-prepared diet; however, their restricted availability prevents their widespread utilisation in UK trout culture.

3.7.3 The use of krill in animal feedstuffs has attracted considerable interest in recent years, particularly the residues left after extraction of the tail meats for human consumption.

Current annual production of krill is believed to be in the region of 120,000 tons p.a. (F.A.O. Fisheries Statistics Circular, 1980), a large proportion of this being taken by the USSR and Eastern European countries where the residues have already achieved some usage in animal feeds. Current production figures are limited by restricted demand for the tail meats rather than by quantities available, and it has been variously estimated that the total international fishery could supply some 5-10 million tons annually (McElroy, 1980). It has further been estimated that krill meal produced from residues could be economically viable at a price of £200-£250 per ton provided that a sufficient market outlet also exists for the more valuable tail meats at £400 per ton (International Association of Fish Meat Manufacturers, 1980). At this price it would be feasible to include krill meal in trout diets as a replacement for fishmeal (See Appendix H), as evaluated by the linear programming model based upon their relative nutritional values as indicated in Appendix G.

Krill meal has been used experimentally to replace fish meal in diets for rainbow trout, carp, coalfish and channel catfish at various levels of inclusion (Koops et al, 1978; von Lukowicz, 1978; Gulbrandsen, 1978; Hilge, 1978) and in the case of rainbow trout proved satisfactory at levels of up to 35% of the diet, although for trout below 16g in weight there appeared to be slightly reduced performances, possibly on account of the high fibre content (Koops et al, 1978). It would appear that the meal used in the study by Koops was full krill meal rather than meal prepared from residues after the extraction of the tail meats. The latter is proportionally higher in chitin, which is believed to be at least partially assimilable (McElroy, 1980).

While krill meal could be of potential use to replace fish meal in trout diets, it is not yet widely available in the UK (other than on an experimental basis), and it seems likely that the use of krill in animal feeds in Western Europe will depend on the concurrent development of a human market for the tail meats.

A rather smaller crustacean, Calanus finmarchicus, has also been proposed as a feedstuff for fish. This copepod, a planktonic species widely distributed along the North-East Atlantic seaboard, has been used to replace fish meal in experimental diets for coalfish but produced disappointing performances (Gulbrandsen, 1979). Calanus has been used by Norwegian saltwater salmon and trout culturists for short periods prior to slaughter in order to pigment the flesh (Ellis, 1979). The small size of C. finmarchicus greatly adds to the difficulties of harvest, and it is therefore unlikely that this material will achieve more than its present local and restricted used as a feed additive.

During World War II Professor Sir Alister Hardy conducted some early investigations into the use of planktonic crustacea as a feedstuff, either for humans or animals, and experimentally harvested these organisms from Loch Fyne, but came to the conclusion that the concentrations involved could not justify commercial exploitation (Hardy, 1978). This was also the conclusion of Jackson (1956) who considered that the engineering problems of harvesting small planktonic organisms would prove too costly for the value of the material obtained. However, where plankton are concentrated incidentally to other operations, such as the filtration of water supplies, it might be possible to use these materials, and at one time a trout hatchery at Glenfarg Reservoir did partially feed fry on the wash water from the reservoir's micro-strainers, although the hatchery has now closed (Crombie, 1978). However, the quantities involved were very small and would not be of great significance except perhaps as an early feed for fry.

3.8 USE OF MEAT AND MEAT OFFALS

3.8.1 Meat and meat offals have long been used in fish culture, and were a very common feedstuff in early trout farming (Bardach et al, 1972; Halver, 1972). These materials are still in use in some places, although largely restricted to relatively small scale units placed appropriately near to a source of supply and also as a supplementary feed for broodstock and for trout (especially brown trout) reared for restocking purposes. The use of dry compound diets has now almost entirely superseded the use of meat and meat offals in the UK, although meat and bone meal is still included in many compound dietary formulations. Meat is also a major component of the wellknown American Oregon moist pellets (Nose, 1979).

3.8.2 Several factors have contributed to the decline in the use of meat in recent years:

1. Improved communications/transport and more efficient fishing methods have combined to reduce the price of fish products relative to those of meat. This trend may now have been halted as a result of the decline in Britain's fishing industry.
2. Increased use of meat offals as pet foods and also as mink foods has raised the amount of competition for these materials (although this applies equally well to many other feedstuffs).
3. Improved compound feed formulations have led to better performance on compound pellets than on meat and offals, a reversal of the previous state of affairs where prolonged feeding on exclusively dry diets tended to cause liver damage in trout (Ghittino, 1979).
4. The larger size of trout farms, as the market becomes increasingly table orientated rather than sport orientated, has reduced the advantages of using meat offals from a local slaughterhouse which may no longer be able to supply the entire farm's requirements.
5. The use of dry compound feeds greatly facilitates farm operations, particularly with regard to storage and

handling (on account of the reduced bulk) and use in automatic feeding systems.

6. Compound pellets from a reliable manufacturer are probably of more consistent quality.
7. Fish products generally contain higher quality protein for fish feedstuffs.

3.8.3 Despite the considerable advantages of dry pellets, there is still a belief in some quarters that the addition of fresh meat as a supplement to a predominantly dry diet improves the condition of trout, and this is reflected in its continued, though much reduced, use in feeding stock trout and broodstock. This practice persists principally in small scale hatcheries. Nonetheless, there may still be occasions when feeding meat and meat offals as a complement to a basal diet or alone may be justified. These situations are summed up by Ghittino (1979) and broadly speaking occur in the following situations:

1. A cheap local supply of offal exists such that the price X the conversion is cheaper than the price X conversion for compound pellets. This is in itself not sufficient justification unless the difference more than compensates for the added expense of transport, storage and handling of the more bulky and perishable wet materials.
2. Meat materials may be added to an incomplete (or low-protein) basal dry ration available at lower cost than a complete dry feed.
3. As a fry food when fish are showing reluctance to accept pellets as a first feed. (Rainbow trout are not generally

handling (on account of the reduced bulk) and use in automatic feeding systems.

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2. Meat materials may be added to an incomplete (or low-protein) basal dry ration available at lower cost than a complete dry feed.
3. As a fry food when fish are showing reluctance to accept pellets as a first feed. (Rainbow trout are not generally

susceptible to this particular shortcoming).

4. As a carrier diet for medicines when ill-conditioned fish are showing reluctance to accept the usual dry diet.

3.8.4 Meat types used are restricted to those that are available at low prices, mainly offals, horsemeat (where not used for human consumption) and condemned carcases (depending upon the circumstances of condemnation). A survey conducted among a number of Scottish slaughterhouses showed that offals could be obtained in quantity at around the following prices in January 1980:

Beef	Thrapple	£ 70 per ton
	Spleen	£ 70 per ton
	Udders	£ 70 per ton
	Lungs	£110 per ton
	Liver	£120 per ton
	Condemned Meat	£120 per ton
Hog	Spleen	£ 70 per ton
	Liver	£110 per ton
Sheep	Liver	£110 per ton
	Tripe	£110 per ton
Chicken	Mixed Offals	Variable
All	Blood	1p to 16p per gall. (See Section 3.9)

3.8.5 The quantities of these materials annually available in Britain were estimated from statistics for the proportion of offals to carcase weight and from EEC statistics on agricultural production, assuming that qualities slaughtered in Britain resemble quantities

TABLE 3.9 ESTIMATED QUANTITIES OF OFFALS ANNUALLY AVAILABLE IN THE UK

	Offal as % by weight of whole carcase	UK Livestock production(1977) (1,000 tonnes)	Estimated UK Offal production (tons)
Hog			
Liver	3.0	905	27,370
Large Intestine (Empty)	3.0	905	27,370
Small Intestine (Empty)	2.9	905	26,035
Lungs & Trachea	2.3	905	20,650
Stomach (Empty)	1.1	905	9,875
Genitals	1.0	905	8,980
Heart	0.6	905	5,390
Cattle			
Large Intestine (Empty)	1.1	1,002	9,940
Small Intestine (Empty)	1.1	1,002	9,940
Heart & Lungs	2.0	1,002	19,880
Liver & Gall Bladder	1.5	1,002	14,910

TABLE 3.9 ESTIMATED QUANTITIES OF OFFALS ANNUALLY AVAILABLE IN THE UK (CONT'D)

	Offal as % by weight of whole carcase	UK Livestock production(1977) (1,000 tonnes)	Estimated UK Offal production (tons)
Cattle (Cont'd)			
Pancreas & Spleen	0.3	1,002	2,980
Blood	3.5	1,002	34,790
Stomach (Empty)	2.5	1,002	24,850
Chicken			
Collectable	10		67,360
Offals	-20	679	-134,720
Sheep			
Collectable	10	223	22,120
Offals	-20		-44,240

*1 Fisher, 1980

*2 Chadwick et al, 1980

*3 Eurostat Yearbook of Agricultural Statistics, 1978 produced. This assumption may not be stricly justified where beasts raised in Britain are transported elsewhere for fattening prior to slaughter. Estimated quantities available are recorded in Table 3.9. Quantities are clearly substantial, although the figures shown overstate the true availability since much of the material is already used for human consumption (e.g. liver and heart; blood in black puddings; stomachs in haggis) or else is produced by small scale or seasonal abattoirs where the supply is insufficiently large or regular to justify its use. It must also be noted that the prices are highly dependent on circumstances, and the prices quoted refer to those materials that are barred to human outlets for one reason or another (condemned meat, surplus supply, etc) and which are therefore used for lower priced markets such as pet foods or meal manufacturers. In some instances, where even these outlets are barred due to geographical isolation of the abattoir, the price could conceivably be lower than this. As an example of this situation, Reawick (Shetland) Lamb Marketing Company, being of a small scale and seasonal nature, has no significant outlet for its offals and therefore attaches less value to them (Barcas, 1980)

3.8.6 Many of the materials available are nutritionally adequate for rainbow trout diets, and especially if supplied as mixed offals should supply most of the essential amino acids, the deficiencies in one material being complemented by surpluses in others. The essential amino acid profiles of selected offals are summarised in Table 3.10.

Both blood and liver contain all the essential amino acids to excess, while beef shows slight deficiencies only in the cystine and methionine content. While amino acid profiles serve as a guide only

TABLE 3.10 ESSENTIAL AMINO ACID CONTENT OF SELECTED ANIMAL OFFALS AS % OF TOTAL DRY MATTER

Material	Protein	Arginine	Cystine + Methionine	Histidine	Isoleucine	Leucine	Lysine	Phenylalanine + Tyrosine	Threonine	Trytophan	Valine	Source
Trout Requirements	42.0	2.4	1.6	0.7	0.9	1.6	2.0	2.1	0.9	0.2	2.1	
Condemned Beef	55.0	4.0	1.5	1.2	2.8	4.6	4.6	3.0	2.2	0.6	3.1	1.2, 3
	+13.0	+1.6	-0.1	+0.5	+1.9	+3.0	+2.6	+0.9	+1.3	+0.4	+1.0	
Blood	90.0	3.9	2.5	4.6	1.1	11.3	7.6	8.7	4.1	1.2	7.1	3
	+48.0	+1.5	+0.9	+3.9	+0.2	+9.7	+5.6	+6.6	+3.2	+1.0	+5.0	
Mixed Liver	72.0	4.4	2.4	1.6	3.7	5.8	5.2	4.9	2.8	0.6	4.5	3
	+30.0	+2.0	+0.8	+0.9	+2.8	+4.2	+3.2	+2.8	+1.9	+0.4	+3.2	
Spleen, Lungs and Intestine	Figures not available											

1. Lawrie, 1971   2. Olson, 1970   3. National Academy of Sciences, 1973

to nutritional value, animal proteins are generally highly digestible by salmonids and the available protein is taken to approximate to the protein content. Blood meal has been suggested to be less digestible in animal feeds than are many other animal proteins (Morrison, 1956), but this may well be a result of the processing methods employed. Trout have been raised for long periods on a diet of clotted blood, indicating that digestibility is at least sufficient for salmonid growth, although the extent to which the excess amino acids might compensate for deficiencies in other materials is open to some question. Salmonid growth has been observed to be inhibited when leucine is fed at three times the level of isoleucine at the required level, while high valine intake also impaired performance (Chance, Mertz and Halver, 1964), and high levels of blood in diets could therefore be damaging.

Liver has generally proved good as a salmonid feedstuff, and has been successfully used since the early days of trout culture. It is not much used currently in the UK, although remaining popular in some countries, where the best materials are reserved for fry and broodstock (Halver, 1972). Beef, spleen and heart are also considered good foods. Hickling (1974) states that liver is a superior food to spleen in general, but that spleen has been found to be of particular benefit in fry diets. Lungs, kidneys, intestines and trimmings are considered to be of lower nutritional value (Halver, 1972).

3.8.7 The performance of fish fed on meat diets has not been satisfactorily decided. Halver (1972) summarises the published literature on conversion of offals into trout flesh and suggests ratios for liver of 2.9-3.3/1 (Phillips et al, 1956), for spleen 2.9/1 (Cornelius, 1933) and for fresh meat (beef) 3.0/1 (Schaperclaus, 1961). Hickling (1974), on the other hand, suggests conversion ratios for mixed offals - liver, spleen and fresh meat - of around 5-8/1. It is probable that the offals used in Hickling's studies were cooked to sterilise diseased tissue, and there is a body of evidence to suggest that cooking may adversely affect digestibility. On the other hand there is a tendency for higher conversion efficiencies to be recorded in laboratory experiments than are found to be the case in commercial practice, possibly as a result of the more closely controlled conditions in the former case. A conversion ratio of around 5/1 for fresh meat and offals would appear to be fairly average, with liver probably superior to spleen and almost certainly superior to lungs.

While an exclusive diet of meat and meat offals may be sufficient to promote growth in trout, many of the modern compound pellets appear to give superior performances, probably on account of vitamin and mineral additives rather than due to superior amino acid profiles.

3.8.8 The product of the price of offals and their expected conversion ratios offers little prospect of using these materials on their own as a trout feed (See Table 3.11).

It should be noted that the conversions suggested for certain of the materials, e.g. lungs, intestine, are in a sense artificial since the inferior nutritional quality of these materials would generally preclude their use as an exclusive diet.

There are three ways in which meat offals might be used in trout diets: they might be fed alone, or with the addition only of such vitamin/binder as is necessary; they might be fed in combination with other materials in a moist compound pellet; or they

TABLE 3.11 COST OF OFFALS (JAN 1980)

Material	£'s per ton	Conversion Ratio	Cost of Trout Produced (£'s/ton)
Blood	2-30	Not known	Not known
Beef Liver	120	5/1	600
Beef Meat	120	5/1	600
Beef Lungs	110	6-7/1	700
Beef Spleen	70	5-6/1	400
Beef Udders, thrapple and intestine	110	6-7/1	460
Hog Spleen	70	5-6/1	400
Hog Liver	110	5/1	550
Sheep Liver	110	5/1	550
Sheep Tripe	110	6-7/1	700
Trout pellets	(See Section 2.3)		(500)

might be fed alongside cheap standard trout pellets of reduced protein content such that the high protein of the offals compensates for the lower protein of the pellets. These three strategies are discussed individually.

3.8.8.1 Use of offals as an exclusive wet feed for trout; (Costs described are those relating directly to feed costs and do not include such items as labour, site overheads, etc, except where these are dependent on the feed type used). Costs relate to a 100 ton per annum trout unit at January 1980 prices.

a) Use of offals from local slaughterhouse, taking daily deliveries using farms existing transport facilities:

Cost of mixed offals	£100 per ton	(Pellets) £290 p/ton
Cost of transport*1	£2.50 per ton	£12.50 p/ton*2
(assuming distance 10 miles)		(Varies with supplier)
Conversion ratio	5-6/1	2/1
Quantity used p.a.	550 tons	200 tons
Cost of feed used p.a.	£56,375	£60,500
Cost of site equipment		
(Mincer/Grinder)	£5,000*3	-
Depreciation on equipment	£715*4	-
Extra labour requirement		
(for hand-feeding of offals)	£4,500*5	-
Total feed costs: Offals	£61,600	(Pellets) £60,050

b) Use of offals from local slaughterhouse, taking weekly deliveries using hired transport:

Cost of mixed offals	£100 per ton	
Cost of hired transport	£5 per ton*6	
Conversion ratio	5-6/1	
Quantity used p.a.	550 tons	
Cost of feed used p.a.	£57,750	
Cost of site equipment:		
Grinder*7	£23,000	
Cold store*8	£7,000	
Annual charge + power:		
Grinder	£2,700	(Section 6.2)
Cold store	£1,760	(Section 3.1)
Extra labour requirement*5	£4,500	
Total feed costs:	£66,710	

(See Appendix I for notes on cost assumptions *1 to *8).

From the foregoing it would not appear that there are economic advantages to be gained from the use of normally priced meat offals in preference to pellets. The addition of premixed vitamin/binder materials would further raise costs, although this might be offset to some extent by improved feed conversions.

In addition to the lower overall cost, compound trout pellets offer a number of advantages regarding their storage properties, ease of use, stability of quality and supply and their reduced pollution loadings. A return to offals as an exclusive feed for trout does not therefore appear justified under prevailing circumstances, while abattoirs capable of supplying the required quantities on a regular year round basis are in any case relatively few in number.

3.8.8.2 Use of offals in moist compound pellets: Offals may be used to best advantage in combination with complementary materials to form a moist compound pellet, as in the case of the Oregon moist diet. Since a number of other materials may be similarly used in this fashion, this usage of meat and meat offals is considered separately in Chapter 6.

3.8.8.3 Use of offals to complement low protein pellets: There are on the market a number of so-called "holding" pellets, relatively low in price and protein content and designed to maintain the fish in good condition but without the extra protein required for growth, used to regulate the trout unit's production timing. By supplementing these pellets with offals, it is theoretically possible to bring the whole diet up to a protein level resembling that of the standard "grower" pellets.

E.g. Standard compound pelleted feed consumed by 100 tons of trout production =200 tons

Protein supplied by 200 tons of standard pellets containing 42% protein =84 tons

Protein supplied by 200 tons of holding pellets containing 35% protein =70 tons

Protein deficit to be made up by supplementary meat and offal materials =14 tons

Weight of mixed offals required to provide 14 tons of protein (assuming wet offals contain 19.5% protein, as suggested by Ghittino, 1972) =71.8 tons of offal.

A 35% protein holding diet could therefore be made iso-proteinaceous with a 42% protein standard diet by supplementing the former with some 72 tons of offals, thus reducing the cost of the pelleted component of the diet at the expense of the supplement required. This might be expected to affect the feed economy of the unit in the following manner; (based on a unit producing 100 tons of trout p.a.) (1980).

Cost of low protein pellets (35% protein)	£220 per ton
Cost of transport*2	£12.50 per ton
Quantity used	200 tons
Total cost of pellets	£46,500
Cost of mixed offals	£100 per ton
Cost of transport*1	£2.50 per ton
Quantity used	72 tons
Total cost of offals	£7,380
Cost of site equipment (Mincer/grinder)*3	£5,000
Depreciation on site equipment*4	£715
Extra labour requirement*9	£2,000

Total feed costs	£56,000

This cost compares favourably with that using standard pellets, and this system is one way of utilising locally available offals to possible advantage. However, the proposed benefits are slight, while the method of use adds to the complexity of farm management and may also adversely affect pollution loadings. Furthermore, there is no guarantee that individual fish would consume each dietary component in the correct balance to ensure nutritional adequacy, and it is quite possible that individuals would select either offals or pellets exclusively, as suggested in Chapter 1. It must also be noted that high protein levels do not necessarily ensure an adequate diet, and amino acid levels should also be adequately compensated. Both of these problems may be more conveniently solved by the use of a moist compound pellet.

3.8.9 The use of meat offals obtained at normal market prices where alternative outlets are available offers little in economic benefits to the trout farmer, either as a sole feed or as a supplement to low protein pellets, but may be useful in moist pellets (Chapter 6). The use of meat offals is fairly close to the economic threshold in some circumstances, and it might prove profitable to feed trout on offals where these may be obtained at significantly less than the usual market price as a result of absence of locally competing interests. These circumstances would be more likely to arise from small scale operations, and under present conditions offals are not likely to provide a viable alternative to trout pellets on any substantial scale.

3.9 USE OF BLOOD

Blood is one of the more promising "offals", being both highly nutritious and relatively cheap. It is unusual among the offals in being in liquid form, and therefore not easily fed fresh unless processed in some manner or added to dry meal components. It is in effect a single-celled protein, and could be considered in Chapter 5 with other single-celled proteins, with which it has much in common, particularly as regards usage. However, it is obtainable from abattoirs alongside those other offals considered in Section 3.8, and it was thus decided to include a discussion of this material here.

3.9.1 Blood has on occasion been used fresh in trout diets. It has a very high protein content and can be mixed with dry low-protein meals to provide an acceptable trout food. Huet (1972) recommends that blood be mixed with white cheese,or with yeast and spleen, to provide a good food for trout fry. There are also instances where clotted or cooked blood has been cut up or minced and fed on its own. Despite these cases, however, the usual method of using blood is as a dried meal, and as such it has been included in many dietary formulations for fish (See Table 6.1) and for other domestic animals.

3.9.2 The use of blood meal is in many respects inferior to the use of fresh blood, adding greatly to the cost. Due to the high water content, reduction of blood to meal is highly energy intensive and is now so expensive that the raw material is virtually worthless when used for this purpose, and it may on occasion be necessary to charge the abattoirs for the collection of blood and to regard its reduction to meal as a waste disposal service (Cooper, 1980), the price realised

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The use of fresh blood could potentially provide therefore a rather better product at a very much lower cost than blood meal, provided that the raw material is reasonably free from unwanted contaminants.

3.9.3 Fresh blood contains around 90% water and 10% dry matter, the quantity of dry matter being made up of almost equal parts of plasma and cellular components. The composition of blood on a dry matter basis is shown in Table 3.10, indicating that all the essential amino acids are present in sufficient quantities to support the growth of trout. However, blood has rather high levels of leucine and of valine, both of which exceed the levels indicated as being acceptable from the point of view of amino acid imbalance in Section 2.5, and it would not therefore be advisable to feed blood on its own for long periods. Furthermore, blood is relatively low in minerals (Huet, 1972) and would almost certainly be best used as a component in a moist feed formulation.

3.9.4 On the basis of a 40% digestibility, as used in the L.P. model described in Chapter 2, blood is of relatively low value on a dry matter basis, in the region of £150 per ton, corresponding to a value of around £15 per ton wet weight. However, at higher digestibilities of around 90%, blood would be a very high value product and worth a similar amount to herring meal, in the region of £270 per ton dry matter of £27 per ton fresh weight (Jan 1980). Since digestibility measurements of blood used in feedstuffs have been concerned with blood meal, the digestibility of blood used fresh is a largely unknown factor and the value of this material might lie anywhere in the region of £15-£30 per ton. There would therefore seem to be a requirement for further study on the digestibility of blood in feedstuffs when used in a variety of ways - fresh, clotted, cooked and spray-dried - as well as for longer term feeding trials to provide further information on the potential value of this material.

3.9.5 The availability of blood has been considered in Section 3.8.5. Its price varies very markedly, and was priced between 1p per gallon, and 16p per gallon in a survey of selected abattoirs in Scotland in 1979-1980, the buyer arranging for containers and transport. The price would seem to depend on whether or not local outlets exist for humanconsumption of blood particularly as regards the manufacture of black puddings and also of pet foods. Where no such outlets exist, the blood may be processed into meal but for reasons mentioned earlier is of relatively low value when used thus. Prices of 1p-16p per gallon correspond approximately to £2-£32 per ton, and in view of the estimated value of blood in Section 3.9.4 it seems that there may be many instances in which blood could be obtained at a price recommending its use locally in trout feed formulations, particularly should the digestibility of blood be found to be superior to that of blood meal.

3.9.6 The manner of use of blood might cause some difficulties on account of its liquid nature, although it may be solidified (jellied would be a better description) if cooked or clotted. Blood could also be ensiled in a similar fashion to fish as described in Section 4.1, but at slightly lower cost due to the reduced equipment requirement (grinding and oil extraction), thus enabling it to be used in circumstances where frequent deliveries of fresh material are not possible.

Due to its high moisture content, and also its very high levels of leucine and valine, blood would be best used in conjunction with dry meals to produce a moist pellet. The maximum level at which blood could be included while maintaining good pelleting properties of the diet is not known, but is likely to be in the region of 40% when used in conjunction with dry meals and a suitable binder only. At such levels of inclusion other materials with which it could be included to provide a diet of sufficient nutritional quality for trout feeding would of course depend on the digestibility of the blood, and the extent therefore to which it could compensate lower-protein vegetable meals.

3.9.7 The use of fresh blood in trout diets shows considerable potential but requires further biological research regarding its digestibility and also long-term feeding trials before it can be properly evaluated. If its nutritional value could be demonstrated, blood could be conveniently included in moist dietary formulations using either fresh or ensiled material. The value of blood meal, on the other hand, is of lesser potential in trout diets, although at present used in a number of formulations, on account of its high processing costs and apparent low digestibility. However, digestibility trials using blood meal are fairly limited, and it may be that with careful processing the quality of the product could be greatly improved, and further trials using this material would therefore be highly desirable.

3.10 USE OF SEAL MEAT

3.10.1 The use of seal meat was considered as a possible source of animal protein in salmonid diets, although it was appreciated from the outset that the quantities available are likely to be relatively small and therefore not suited to use on a widespread basis.

At the time of writing seal culling in Scotland has an uncertain future, although it appears highly probable that it will continue in some form should the existing grey seal populations increase further.

If one makes the tentative assumption that culling will be carried out with the intention of restricting populations to their present levels, then a potential crop of nine hundred adult seals might be expected to be available for a number of years to come (Campbell, 1979), with perhaps an equal number of pups. (Projections of the total number to be culled and the expected ratio between adults and pups are highly uncertain and may be expected to vary markedly from year to year according to climatic conditions and the ease of landing on the breeding islands during the comparatively short season when the pups are land bound).

From the above projections on likely culling levels, an estimate of the probable quantities of seal meat available annually may be made:

No. of adult seals	- 900
Weight of adult seal	- 450 lbs
Weight of flensed carcase	- 300 lbs
Total weight of adult carcases	- 270,000 lbs
No. of pups	- 900
Weight of pup	- 80 - 110 lbs*
Weight of flensed carcase	- 50 - 70 lbs*
Total weight of pup carcases	- 54,000 lbs
Total weight of all carcases	- 324,000 lbs or 162 tons p.a.

*Weight varies with the time of the season at which they are taken.

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While the quantity involved is clearly far too small for general use, it might nonetheless be sufficient to permit small scale use locally should the material be available at a low enough price.

3.10.2 The value of seal meat as a protein feedstuff has received attention in some parts of the world, although work in Britain on the native grey seal here considered lags behind in this respect. The approximate composition is as shown in Table 3.12. The amino acid composition is uncertain but is expected to be similar to the values shown in Table 3.13, obtained for other species elsewhere. Le Roche Chemicals, Canada, from their own amino acid tables, suggest that compensation of seal meat meal as a feed for salmonids would raise no difficulties (Section 2.5). Should seal meat meal be used as an additive in a compound fish feed, then it would in any case be compensated by the other materials used and/or by additives as a matter of course.

3.10.3 Investigations suggest that the seal hunters involved in the culling would be prepared to retain the carcases along with the skins, although the price at which it would become worthwhile to do so is complicated by a number of factors.

In some cases the carcases would have to be dragged overland across the breeding islands for up to a mile to the boats, and while the flensed skins are already taken such distances as the occasion demands, to take the carcase as well would necessarily reduce the number of pelts that could be taken in the same period. Considering the extra weight involved in retaining the whole carcase, it is probable that, despite the small saving in time resulting from not having to flense the animal, approximately half the normal number of pelts could be taken in the limited time period that the hunters are able to stay on the island (Barbour,1979).

Over the past few years an unflayed sealskin as it comes off the island has varied in price from £5 to £7 for a pup, and this

TABLE 3.12 APPROXIMATE COMPOSITION OF SEAL MEAT COMPOSITION AS PERCENT OF DRY MATTER

Protein	78.1
Fat	8.4
Crude Fibre	0.3
Ash	4.4
Gross Energy (KCal per Kg.)	5634

TABLE 3.13 APPROXIMATE AMINO ACID ANALYSIS (SEALS) PERCENT OF DRY MATTER

Arginine	2.49
Cystine	-
Histidine	1.30
Isoleucine	2.97
Leucine	4.67
Lysine	5.00
Methionine	1.80
Phenylalanine	2.25
Threonine	1.75
Tryptophan	0.89
Tyrosine	-
Valine	3.07

is therefore taken as being the price required for the carcase also were this to compensate for the reduced number of pelts taken.

The matter is further complicated however by the fact many of the hunters frequently achieve a cull far less than the number for which the licence is issued on account of adverse conditions, and there is a real fear among such licensees that to fall further behind their quota by collecting the carcases could prompt the Department of Agriculture and Fisheries for Scotland to reduce the numbers for which they are licensed and/or re-allocate the licences. Incidentally such an action would contrast with and further harm the DAFS own stipulation that all culled carcases should be suitabley disposed of in order to avoid giving offence to the public, either by burying, burning or removal to a fish meal processing factory. In point of fact however there is considerable evidence that the DAFS stipulations are widely ignored, especially in cases where the hunters have fallen behind their quota. Where the DAFS stipulations have been observed, there are occasions when the hunters have considered it easiest to dump the carcases at sea (e.g. as with certain Norwegian hunters in 1977), and in such cases the extra cost of transport of the carcases to the boats is borne anyway whether they are to be eventually used or not. Thus it could be said that were the DAFS stipulations more strictly observed and/or enforced, then the prospect of utilising the carcase along with the flensed skin would be considerably enhanced.

The foregoing refers largely to the pups. The adult cows have a lower skin value relative to their bulk, and where pups are scarce it might therefore be possible to obtain the adult seals at a lower unit weight cost. In addition there are times when the hunters arrive on an island to find only a few seals left, and it would then be worthwhile to take the carcases along since no further pelts would be foregone by this action. The effect on the price of the carcase will probably be slight however (Young, 1979).

The cull as previously practised is highly seasonal in nature, lasting from about mid October to mid November in the Hebrides, or slightly later off the Northern Islands (Shetland, Orkney). Unless therefore used as a fresh minced feed at this time, the carcase would require to be either frozen or reduced to a meal. For pups costing between £5 and £7 per carcase (approximately 10p per lb fresh weight) this could clearly not be competitive with existing meal (currently costing around £200 per ton (10p per lb) and £250 per ton (12½p per lb) dry weight respectively). (Dec 1979 prices). Furthermore the very high transport costs involved in freight from the Western Isles would mitigate against the use of this material on the mainland, although conversely the same factor would encourage its use locally on the islands where it is the imported compound feedstuffs that must currently bear this freight charge.

The use of seal meat as a fish feed presents other problems whose magnitude is at present hard to assess. The vehemence of objectors to seal culling must be considered, and this is cited by a fish meal factory at Bressay, Orkney, as a major factor in their decision at Autumn 1978 not to proceed with plans for the reduction of seal meat to meal form. On the other hand the Department of Agriculture and Fisheries for Scotland regard it is desirable from the public relations angle to put the flesh to good use. Certainly the use of seal skins only for what are in many cases trivial uses in making souvenir trinkets has aroused a great deal of criticism in recent years. It is therefore open to some question whether use of seal meat as a feedstuff would in general be welcombed or opposed by be foregone by this action. The effect on the price of the carcase will probably be slight however (Young, 1979).

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A further problem concerning the use of seal meat as a feed for animals eventually destined for human consumption is the accumulation of certain harmful organochlorines (dieldrin, DDT and PCB) that have been observed to occur in the tissues of British grey seals. This problem is receiving some attention from the Seals Research Division of the National Environmental Research Council, but current knowledge is inadequate to permit reasonable comment to be made at this stage on the extent of the hazard.

3.10.4 This consideration of the use of culled seals as a feedstuff for salmonids is necessarily brief since little published information is available on the subject. However, it would seem that grey seal meat is unable to compete effectively with existing animal protein feeds such as fish meal and meat and bone meal. This view is in accordance with that of the Department of Agriculture and Fisheries for Scotland, who state that such indications as they have suggest that use of the meat is uneconomic.

The use of this material remains a possibility for the future, however, although it is probable that it could only become economic if the DAFS were to enforce proper disposal and/or use of the carcases for social reasons. In such a situation seal meat could contribute to local feedstuff requirements, but high transport charges and the limited quantities produced would continue to mitigate against more widespread uses of this material.

CHAPTER 4

Use of single cell protein and novel plant materials

4.1 SINGLE CELL PROTEINS (S.C.P.)

4.1.1 The term "single cell protein" is taken to encompass a number of products derived from micro-algae, yeasts and bacteria, whether or not the product in fact consists of whole single cells. Single cell proteins have recently achieved some measure of acceptability within the agricultural feedstuff industry and have been produced on pilot and industrial scales by a number of UK commercial concerns (Table 4.1).

TABLE 4.1 S.C.P. PRODUCTION IN THE UNITED KINGDOM

Company	Organism Cultured	Substrate	Est. Prod (1980)
British Petroleum	Yeast	n-paraffins	Discontinued
ICI	Bacteria	Methanol	10,000 tons (J Hood, P.C. ICI Agric Div)
Shell Chemicals	Bacteria	Methanol	Discontinued
R.H.M. Foods	Fungi	Carbohydrates	Not Known
Tate & Lyle	Fungi	Carbohydrates	Not Known

The biological feasibility of producing protein from hydrocarbon fermentation has been recognised since the beginning of the century. However, it is only since 1959 that BP, followed by a number of other companies such as Tate & Lyle and ICI and also by some government agencies elsewhere, has become involved in the development of a continuous production process using "waste" hydrocarbons (in BP's case, underutilised petroleum factions such as the n-paraffins). The S.C.P. materials currently or recently produced in the UK are listed in Table 4.1. Production methods are superficially described by a number of authors (Watts, 1976; Humphrey, 1970; Cooney et al, 1975; Beatty, 1974; Senez, 1972; Shacklady, 1975) although much of the detail remains the knowledge of the developing companies. The subject is reviewed according to the knowledge of the time by Davis (1974).

4.1.2 Wang (1968) attempts to cost the production of single cell petro-proteins on a variety of petroleum faction substrates, and derives costs similar to those prevailing for conventional protein at that time. Economic viability depends on the price of the substrate, the capital cost of the plant, the efficiency of conversion, production and processing/drying costs and the price realised by the product, this last being highly dependent on the cost of conventional protein sources. Since then, relative movements in the price of oil and conventional feedstuffs have resulted in a reduction in the economic viability of some petro-proteins (Watts, 1976), such that of those companies listed in Table 4.1, single cell proteins are now produced in the UK by ICI and RHM foods only, the latter producing S.C.P. intended for human consumption.

The production of single cell proteins from "waste" carbohydrates is likely to remain close to economic viability for some time. The production of S.C.P. for direct human consumption on the other hand requires expensive treatments for the removal of excess nucleic acids (harmful to primates) as described by Rolfe (1976). This being so, the human consumption market is unlikely to starve animal feed production of raw materials. Watts (1976) indicates that at that time the entire world consumption of protein could in any case have been met by less than 5% of the total world oil consumption, such that the potential size of the industry is tremendous. Matty and Smith (1978) suggest that the EEC could be producing 60 million tonnes of S.C.P. by 1985 on the basis of profitability at that time.

Industrial production of S.C.P. on petroleum substrates is a highly capital intensive business, and has so far only appeared either attractive or feasible to very large companies or government agencies with a large and guaranteed supply of cheap raw materials. Tate & Lyle's approach, in contrast, involves relatively low capital investment, but still depends on a good supply of raw materials (carbohydrate). The production of S.C.P. is not considered to be a viable propostion to the individual fish culturist in the UK, although the biological (but not commercial) feasibility of culturing yeast on more widely available substrates such as manure solubles has been demonstrated by Singh and Anthony (1968). Algae may be successfully cultured by a very much less capital intensive system, but is not believed to be suitable for the UK on account of the relatively low levels of illumination received at this latitude (Smith, 1976).

4.1.3 Such algal materials as are cultured in the UK for use as feedstuffs, e.g. for oyster, rotifers, etc (Scott and Baynes, 1979) are intended for temporary fry/larval feeding only and are not suitable for the production of large quantities of low priced feeds. Even where climatic conditions are suitable for the outdoor mass culture of algae, as in Israel, the high cost of harvesting and drying has so far inhibited the use of this material, preventing it from being competitive with conventional protein sources, (Hepher et al, 1979), and algal cultures are more economically utilised where they may be

TABLE 4.2 COMPOSITION AND PRICE OF SINGLE CELL PROTEIN

	Arginine	Cystine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Tyrosine	Valine	Water	Protein	Fats and Oils	Fibre	Carbohydrate	Ash	£ per ton 1981, Jan	Source
A.S.C.P. (D.M.)	1.7	0.3	0.7	1.5	2.7	1.8	0.3	2.2	2.0	-*1	0.8	2.3	0.0	41.0	1.9	11.2	10.6	35.5*2		Tacon & Fern (1976)
A.S.C.P. (Meal)	1.6	0.25	0.7	1.4	2.5	1.7	0.25	2.1	1.9	-	0.7	2.2	7.85	37.8	1.73	10.3	9.80	32.52*2		" "
ICI "Pruteen" Meth. Bact. D.M.	3.7	0.4	1.4	3.3	5.0	4.6	2.1	2.7	3.3	0.6	2.4	3.9	0.0	80.2						Kaushil & Luquet 1980
ICI "Pruteen" (Meal)	3.4	0.4	1.3	3.1	4.6	4.3	1.9	2.5	3.1	0.6	2.2	3.6	7.5	74.2	7.5		8.3	10.0	£240	ICI Per Comm
BP Yeast (D.M.)	3.3		1.4	3.2	4.8	4.9	0.7	3.8	3.2	0.9	1.3	3.8	0.0							Smith 1976
BP Yeast (Meal)	3.1		1.3	3.0	4.5	4.6	0.7	3.5	3.0	0.8	1.2	3.5	7.0							
Symba Yeast (D.M.)	FIGURES NOT AVAILABLE																			Bergstrom, 1979
Symba Yeast (Meal)																				

*1 Believed destroyed during acid hydrolysis.

*2 Tacon's original figures did not add up to 100%. It is presumed that this was as a result of non-protein nitrogen being counted twice - as crude protein and as ash. Ash being virtually inanimate in dietary formulations, is therefore adjusted accordingly.

*3 All values depend on method of analysis, and may be low where acid hydrolysis is used.

used on site without further processing, i.e. by piping the algal cultures directly into the fish culture pond. An integrated pig or poultry unit and algal cultivation on the animal "wastes" has been proposed by Wayman (1973) but has yet to be demonstrated commercially, and would presumably also be restricted to more central latitudes.

The production and capital costs of S.C.P. culture units is not discussed further in this thesis. Instead, with the exception of activated sludges which are considered later, attention is concentrated on the major manufacturers' brands of S.C.P., in particular as regards their purchase price, their biological acceptability in trout diets and their probable monetary value as suggested by their performance in trial diets and in linear programming models.

4.2 NUTRITIONAL VALUE OF SINGLE CELL PROTEINS IN TROUT DIETS

The nutritional values of a variety of single cell proteins have been demonstrated for trout and for certain other fish species in a number of recent papers.

Algal proteins have been used to partially replace conventional protein sources in trout diets at relatively high levels with varying degress of success. Smith (1976) included algal meal at levels of up to 40% by weight, and in one trial used a diet containing 25% protein derived solely from algal meal to produce a food conversion in the region of 2/1. However, food consumption and growth rate were both much reduced in this instance. Matty and Smith (1978), using algae (Spirulina sp.) again as the sole protein source in trout diets, also found reduced growth rates and poor conversion efficiencies compared with diets based on fishmeal protein sources. Atack and Matty (1979) similarly found reduced growth rates and food conversion when algal meal was included at 52% by weight of the diet as the sole protein source. Matty and Smith suggested the sulphur-amino acids methionine and cystine as being limiting when diets contain high levels of algal proteins are fed, being supported by proximate and amino acid analyses of these materials. Nonetheless, as Smith (1976) points out, there is need for confirmation that the amino acids indicated as limiting on the basis of chemical nutrient analyses are in fact the same as those actually limiting in practical fish diets.

In addition to work involving rainbow trout, other studies have been conducted on the inclusion of algal meals in a number of warm water fish diets (Reed et al, 1974; Stanley and Jones, 1976; Meske and Pruss, 1977; Henheretal, 1979), and it may be that algal feed materials will be found more suitable for inclusion in diets for herbivorous fish species than for the naturally carnivorous trout. The relatively low protein content of some algal products and their poor digestibility compared to many animal proteins may severely limit the use of these materials in trout feeds, since their inclusion at any substantial level will result in reduced overall protein content of the diet, lower than that shown to be optimum for salmonid growth.

Nutritional studies involving the use of fungal and bacterial proteins in trout diets are more numerous and show considerably more promise. Alkane grown yeasts, supplemented with methionine, have been successfully included in trout diets at levels of 35.8% and 72% by weight (Beck, Gropp, Tiews and Koops, 1979), at the latter level yeast plus supplementary methionine constituting the sole protein source of the diet. Growth rates and food conversion efficiencies were in both cases comparable with those obtained using diets containing protein derived from fish meal and poultry by-product meals, being lowest (3% difference) in the diet containing 72% yeast. Atack and Matty (1979), using unsupplemented petro-yeast ("Toprina" - BP Proteins Ltd) and brewer's yeast (yeast blend from Wrigglesworth Feedstuffs Ltd), found that the petro-yeast produced comparable growth to herring meal based diets, but that the brewer's yeast's performance was decidedly inferior. The good performance using petro-yeast was achieved despite the apparent deficiency of sulphur amino acids, and the authors conclude that petro-yeasts could be used to replace a substantial proportion of the fish meal used in diet formulations. The test period over which the trials were conducted was of a fairly short duration (8 weeks) and it is possible therefore that the effects of deficiencies in cystine and methionine might show up over a longer growth period. Matty and Smith (1968) draw similar conclusions on the use of yeasts in trout diets, finding growth rates and conversion efficiencies similar to those obtained using fish meal based diets, and suggest, as do Gropp and Bohl (1976), that high-protein yeasts could be used in lieu of a large part of conventional fishmeal protein sources. Smith (1976) included petroleum grown yeast (*Candida lipolytica* - BP) at a level of 40% by weight of the diet with no apparent adverse effects on growth when 20% herring meal was also included in the diet, whereas two other fungi tested - (*Aspergillus niger*) and (*Penicillium chrysogenum*) - performed less well when included at 20% of the diet and were markedly inferior at the 40% level in terms of both growth rate and conversion efficiency. Nose (1979) suggests that alkane yeasts, methanol yeasts and ethanol yeasts (i.e. petro-yeasts) may be included in trout diets as replacement for fish meal on an isonitrogenous basis to a level of about 30% without any noticeable suppression of growth. Yeasts have also been used to replace casein in fish meal free rainbow trout diets (Andruetto et al, 1973).

Brewers' yeasts have long been included in certain trout diet formulations as a source of vitamins, but their low protein content relative to petroleum-grown yeasts severely limits their use as a major protein contributor, requiring to be balanced by other high protein feedstuffs to enable an overall protein content of the feed approaching 40% to be achieved. (Smith 1976; Atack and Matty, 1979).

The first limiting amino acids of both petro-yeasts and brewers' yeasts as regards their usefulness in salmonid diets would appear to be the sulphur-amino acids cystine and methionine (Atack and Matty, 1979). Yeasts have also been studied as potential fry diets for some species (Appelbaum, 1979).

Sutdies on the use of bacterial protein in salmonid diets have produced somewhat contradictory results. Most have concentrated on the use of methanophilic bacteria, and in particular on ICI's novel protein material "Pruteen".

Smith (1976) found reduced performance when fish meal was replaced by ICI bacterial material in trout diets, and suggests that the poor palatability observed during the course of the trials may be in part responsible. Matty and Smith (1978) similarly found a reduced level of performance when bacteria (Pseudomanas sp) were used as the sole protein source, the growth rate of the fish in particular being 50% lower than for the control diet (a commercial pellet). Appetite quotients were also markedly lower. Atack and Matty (1979), on the other hand, again using "Pruteen" as the sole protein source in diets, concluded that this material produced good conversion, digestibility and acceptability despite the apparent deficiency of the sulphur-amino acids cystine and methionine (estimated as being 75% of the stated salmonid requirement in the test diets). This is supported by Kaushik and Luquet (1980), who included "Pruteen" in rainbow trout diets at levels of up to 35% in conjunction with 22% soya bean meal, replacing the fish meal component entirely. Feed intake, growth and conversion efficiency were good as long as the bacterial component remained less than the fish meal component, but were adversely affected when S.C.P. was included at levels such as to constitute the major protein source. Digestibility conversely appeared to increase with increasing levels of S.C.P. in the diet. Supplementation with cystine and methionine (individually) did not improve performance and actually appeared to reduce growth. However, in these supplementation trials S.C.P. was included at 14% of the diet only, and in conjunction with fish meal, such that the sulphur-amino acids were only marginally limiting. Bergstrom (1979), working with salmon fry, concluded that up to a third of the fish meal in compound diets could be replace by unsupplemented bacterial protein without apparent detrimental effects on growth. Beck, Gropp, Koops and Tiews (1979) found that replacement of a third of the fish meal with bacterial protein resulted in improved growth and feed efficiency, but that at higher levels the results were inconclusive and somewhat contradictory. Supplementation of the bacterial protein with methionine of arginine individually failed to improve performance, whereas supplementation with both these acids together did affect growth and feed conversion, suggesting that methionine and arginine were equally limiting in diets containing substantial quantities of bacterial protein. Smith (1976) on the other hand suggests that the methods now commonly used for amino acid determinations frequently involve acid hydrolysis of the protein, and that this can be responsible for the oxidation and/or destruction of methionine and more particularly cystine, and that this may result in low values in the literature for these acids.

As with algal proteins, it may be that bacterial protein might be more suitably employed in feeding less exclusively carnivorous species than the trout. Ohmae (1975) quoted by Nose (1979), found better growth rates in carp using diets containing methanol-grown bacteria as the sole protein source than using diets containing fish meal as the sole protein. The Japanese Fisheries Agency (1973) similarly showed that a diet containing petro-yeasts and fish meal produced better growth in carp than did a diet containing fish meal alone.

Activated sewage sludge (activated single cell protein of some authors - A.S.C.P.), being a mixture of micro-organisms, does not fit conveniently into any of the three categories (algae, fungi and bacteria) and is discussed separately.

4.3 DIGESTIBILITY OF SINGLE CELL PROTEINS

Digestibility of proteinaceous materials by rainbow trout has only recently begun to receive detailed attention in the field of feed formulation, and little comparable data as yet exists. A number of conventional protein materials have been shown to vary quite markedly (e.g. between 77% and 98% for herring meal), depending on the batch tested, processing methods employed and testing procedure. Hepher et al (1979) for instance found that drum dried algal material was digested some 10-15% better than sun dried material when fed to rainbow trout, possibly as a result of increased rupture of the cell walls. The S.C.P. materials currently available on the British market are produced by a small number of large companies, such that the quality control may be expected to be stringent and the true digestibility fairly consistent. Reports from various authors may still vary somewhat as a result of the methods used to test digestibility or the environmental conditions prevailing during the test period.

Smith (1976) attempted to measure the digestibilities of the single cell proteins used in his work. More recently, Atack and Matty (1979) have reported the following protein digestibilities recorded for their test materials:

Petroleum Yeast	91.6%
Methanophilic Bacteria	93.5%
Spirulina Meal	83.1%
Brewers' Yeast	79.9%

4.4 CONCLUSIONS ON THE USE OF SINGLE CELL PROTEINS

It was initially intended that a number of S.C.P. materials should be evaluated by linear programming methods as described in Chapter 2. Unfortunately this was not possible due to difficulties in obtaining reliable amino acid analyses of the product, which were not available until a late stage.

On the basis of those feeding trials described in Section 4.2, it is apparent that the majority of single cell proteins produced are not sufficient alone to provide a complete diet for trout, being deficient particularly in the sulphur-amino acids cystine and methionine. While a number of authors have suggested that S.C.P. may be used to replace fish meal in diets in varying amounts, which would in effect confer upon the S.C.P. a value identical to that of the fish meal which could be thus replaced, these authors neglect to point out that the fish meal present in the original basal diet is in most cases considerably in excess of requirements and much of it could instead have been replaced by cheaper dietary ingredients. When used in fish feeds, however, many of the S.C.P. have been found to be well accepted and to provide good water stability in the pellets, with the possible exception of Aspergillus sp.(Smith, 1976). However, a certain amount of non-lethal lipid degeneration was reported by Smith (1976) after periods of feeding trout on high levels of bacterial protein, and high levels of inclusion would not therefore be recommended.

In the absence of a full L.P. evaluation, the only S.C.P. animal feed currently produced in the UK in significant quantities - ICI's Pruteen - is likely to have a market value between that of good quality soya meal (49% protein) and white fish meals, having levels of the usual limiting amino acids (cystine, methionine and lysine) intermediate between these two products (see Table 4.2 and Appendix E), but being closer to soya meal. It is suggested that a likely market value for "Pruteen" in trout feeds would be around £210-£220 per ton, compared with the January 1981 market price of £240 per ton. It is not likely therefore that S.C.P. will become widely used in trout feeds in the near future, providing more suitable feeds for cattle and other predominantly vegetarian animals which thus largely determine the market price. However, the proven acceptability of this material in trout diets indicates that these materials could become important components in trout diets should their price become more favourable relative to competing protein materials.

4.5 DIRECT USE OF ACTIVATED SLUDGE

The direct use of single cell proteins in animal feedstuffs and in rainbow trout diets has been examined in a number of studies in recent years, notably those by Tacon and Ferns (1976) and Smith (1976). Particular interest has been shown in the use of activated sludges, derived either from domestic sewage (Tacon and Ferns, 1976) or from other processes such as paper processing (Orme and Lemm, 1973). While the majority of such studies have come to the firm conclusion that activated sludges could provide a potentially important feedstuff, and in substantial quantities, problems remain concerning the levels at which these substances may be best included in the diets, the cost of dewatering and drying the sludges, hazards relating to pathogens and heavy metals contained in the materials, and possible consumer resistance and/or governmental intervention.

Tacon (1979) is reported to have included activated sewage sludge in test trout diets at levels of up to 33% by weight with no apparent fall in growth rates of the fish or decline in feed conversion efficiency, while Tacon and Ferns (1976) provide a valuable paper on the use of activated single cell protein (ASCP hereafter) in trout diets which it is appropriate to consider further at this stage.

Tacon and Ferns made up a number of experimental diets containing 5%, 10% and 20% ASCP by weight and compared their performance over a thirty five day feeding trial with a control diet containing no ASCP but containing materials in similar proportions to

TABLE 4.3 COMPOSITION OF ASCP USED IN TRIALS BY TACON AND FERNS

Water	7.85%
Crude Protein	37.80%
True Protein	31.25%
Fat	1.73%
Ash	25.16%
Acid Insoluble Ash	12.33%
Carbohydrate (As Glucose)	9.80%
Fibre	10.30%
Gross Energy Value (kj/g)	16.20
METALS	
Ca	2.73%
P	1.42%
Fe	1.37%
Al	0.75%
Mg	0.36%
K	0.34%
Na	0.12%
Mn	910 ppm
Zn	740 ppm
Cu	360 ppm
Pb	81 ppm
Ni	38 ppm
Cr	32 ppm
Cd	4 ppm

TABLE 4.4 AMINO ACID CONTENT OF ASCP USED BY TACON AND FERNS

	Percent
Aspartic Acid	2.86
Serine	1.40
Glutamic Acid	3.62
Proline	1.28
Glycine	2.26
Alanine	2.95
Cystine[1]	0.25
Tyrosine	0.72
Threonine	1.86
Valine	2.19
Methionine[1]	0.25
Isoleucine	1.42
Leucine	2.47
Phenylalanine	2.07
Histidine	0.69
Lysine	1.68
Arginine	1.59
Tryptophan[2]	-

1 These values may be low. It is advisable to use the performic oxidation method for the preparation of samples for cystine and methionine analysis. (Tacon and Ferns).

2 Destroyed during acid hydrolysis. (Tacon and Ferns).

those found in standard commercially prepared trout feeds. All diets were adjusted to contain 45% protein and 6% fat, although no attempt was made to balance the levels of ash, fibre and carbohydrate.

Analysis of the ASCP used and amino acid analyses are reproduced in Tables 4.3 and 4.4. It should be borne in mind, however, that ASCP is extremely variable in content and can vary both from one day to the next as well as between different sources, particularly as regards the percentage dry matter and the heavy metal content, and especially when heavy rain increases the surface run-off that most sewage systems have to deal with.

The performance of all four groups of trout is summarised in Table 4.5, and from the results obtained the paper concludes that growth and conversion efficiencies were not adversely affected by inclusion in the diet of ASCP at levels of up to 20% by weight. The test diet containing 20% ASCP therefore effectively replaced 8% white fish meal and 12% wheat middlings.

These results are in accordance with those of other studies using activated sludge materials derived from other sources, and further work by Tacon has included ASCP in trout diets at levels of up to 33% by weight without apparent adverse effects on either growth rates or food conversion efficiency.

Orme and Lemm (1973) ran similar trials using activated sludge derived from an American paper processing plant. (For composition of the sludge, see Table 4.6). They fed three diets containing 0%, 25% and 50% by weight of the dried sludge, feeding level based on a constant daily weight of 7.7% of the projected weight of the fish. The period involved (285 days) forms a very substantial part of the average period to grow trout to full market size in trout farms, and projection of the results can thus be made with some confidence.

TABLE 4.5 PERFORMANCE OF RAINBOW TROUT FED ON TEST DIETS CONTAINING ACTIVATED SEWAGE SLUDGE (Tacon and Ferns)

(Mean Values)	Control	5%	10%	20%	±SE[1]
Initial Weight g.	15.69	17.18	19.13	17.91	0.354
Final Weight g.	26.47	26.20	32.06	30.60	1.410
Weight Gain g.	10.78	9.02	12.93	12.69	
Food Conversion	1.10	1.17	1.10	1.07	0.080
Protein Efficiency Ration[2]	2.10	1.80	2.03	2.13	0.140
Blood Parameters					
Haematocrit %	36	35	38	36	0.500
Haemoglobin (g. per 100 ml.)	9.25	8.00	9.50	9.00	0.180

1 SE calculated from residual mean square in the analysis of variance.

2 PER defined as g. protein gained per g. protein consumed.

TABLE 4.6 COMPOSITION OF DRIED SLUDGE FROM PAPER PROCESSING PLANT (FROM ORME AND LEM, 1973)

Crude Protein	42.32%
Crude Fat	0.43%
Moisture	3.03%
Ash	27.69%
Fibre	10.56%
NFE (Difference)	15.97%
Amino Acids	
Arginine	3.07%
Glycine	3.11%
Histidine	0.90%
Isoleucine	2.05%
Leucine	3.50%
Lysine	2.07%
Methionine	1.20%
Phenylalanine	2.02%
Threonine	2.23%
Tryptophan	-
Tyrosine	1.51%
Valine	2.69%
Cystine	0.14%
Glutamic Acid	5.07%
Aspartic Acid	4.42%
Serine	1.74%
Proline	1.63%
Alanine	3.85%

The trout are again reported to have fed well on all three diets. However, unlike the results of Tacon's work on domestic sewage sludges, Orme and Lemm found that the conversion efficiency and growth rates decreased as the percentage of sludge in the diet increased from 0% to 50%, despite the fact that both test diets contained higher levels of arginine and phenylalinine than the control diet which contained levels slightly below the suggested requirement of trout for these amino acids.

While some doubt thus remains on the quality of ASCP in trout diets, the work that has so far been done indicates that these materials may be included without impairing acceptability of the diet or adversely affecting the fishes' health, and the question remaining is more one of the value of these materials in dietary formulations.

Accordingly, ASCP was evaluated by the linear programming model outlined in Section 2.5.1, using the composition recorded in Appendix G, being derived from Tacon and Ferns analyses reported in Tables 4.3 and 4.4 and adjusted for the water content. This material was found to have a value of around £115 per ton of dry matter when used in combination with the other ingredients as described in Section 2.5 at Jan 1980 prices and assuming 90% digestibility, at which price it could economically constitute some 34% of the diet (Appendix H). At 80% digestibility, its value would be reduced to around £105 per ton of dry matter.

Of some particular interest is its reverse sensitivity to the price of herring meal, indicating that this is a complimentary item and that these two ingredients may compensate one another to some extent. Its apparent lack of sensitivity to white fish is due to the latter's exclusion from the basal scenario due to its high price relative to herring meal at the time of evaluation. ASCP's normal sensitivity to meat and bone meal is much as might be expected, and these two items would appear therefore to be competitive to some degree. Sensitivity of ASCP to soya meal was unfortunately not investigated, but it is expected that this too would show normal sensitivity indicating a partially competitive nature, i.e. where one item might partially replace another when relative prices change.

The precise digestibility of ASCP is not known, and will of course in any case vary substantially with the method of processing, the initial composition and possibly also the nature of the ingredients with which it would be combined in a diet. However, even at 90% digestibility, and a value of £115 per ton (dry matter), it is unlikely that the production of a meal from activated sludge will prove economically feasible on account of the very high initial water content of the material. The water content of ASCP is usually around 99% or greater, unless partially dewatered prior to disposal for purposes of transport. The small size of the particulate matter makes filtration impractical, since the filter medium becomes so quickly clogged, and it is suggested that ASCP would have to be reduced to meal by means of spray drying, in a similar fashion to dried milk products and blood meal. However, such processing methods are extremely expensive - so much so that blood meal, having a very much higher end value than ASCP, is on the limits of economic viability and is prepared largely as a disposal service to slaughterhouses, the raw material now being virtually worthless (See Section 3.6). This being the case, it is considered to be uneconomic at present to process ASCP into meal form, unless the raw material has already been partially dewatered to facilitate disposal. In this respect, it is perhaps worth noting that activated sludges have in the past been dewatered to levels of 4% dry matter prior to disposal at sea via tankers, but that even at this level I am informed that it would not be economic to reduce this material to meal at a price commensurate with its use in agricultural feedstuffs, at least not by employing the standard methods used in blood meal and dried milk production. (Cooper, 1980).

It is therefore seems that the direct use of activated sludges in trout diets is impractical given the current level of dewatering at treatment. Nonetheless, continual improvements are being made in the processing of sewage sludges with a view to facilitating disposal, and centrifugation of the sludges in particular is now receiving attention (Anon, 1978), and it may be that ASCP will become sufficiently dewatered to become economically useful in the future.

Should this ever prove to be the case however, there are still considerable problems concerning the use of ASCP, particularly with regard to public health aspects both from the possible transmission of human pathogens and harmful concentrations of heavy metals. There does not appear to be any published work on the passage of pathogenic materials through trout. However a number of studies have been conducted on the use of sewage sludges as agricultural fertilisers. Lockett (1945) suggests that the majority of pathogenic organisms are destroyed during purification of sewage by the activated sludge process, but that Salmonella appears able to survive to a degree, and it is unlikely that sewage sludge could be included directly in agricultural feedstuffs without a great deal more testing.

The potential concentration of heavy metals is in a rather different category since the original levels in the raw sewage vary widely depending on the nature of local industry and the regional geology. It seems probable therefore that the acceptability of ASCP with respect to heavy metal concentrations would require to be investigated on the basis of individual sewage works. The extent to which various metals are concentrated in trout flesh has been studied by Tacon (1979).

A further unknown factor with regard to the inclusion of ASCP in trout diets is the effect it may have on public acceptability of trout.

On the basis of the foregoing, the direct use of ASCP in trout feedstuffs on a commercial basis appears unlikely in the near future, and sewage sludges might be better utilised indirectly in the production of intermediate food organisms produced in close proximity to the sewage works (See Chapter 5). Nonetheless, ASCP will probably continue to attract considerable scientific interest, and the potentially very large quantities available make this material worthy of continual reappraisal.

4.6 USE OF DISTILLERS' AND BREWERS' RESIDUES

Interest has been expressed in recent years by a number of Brewers and Distillers in the potential of grain and yeast by-products for use in aquaculture feedstuffs. These by-products, recovered after production of alcohol, include the following materials:

Distillers' Residues	Water %	Protein %	Est.Ann.Prod.[1] (Scot.Dry Tonnes)
Spent Grains + yeast residues			98,500

Distillers' Residues (cont)	Water %	Protein %	Est.Ann.Prod.[1] (Scot.Dry Tonnes)
Distillers' Dried Solubles	5[*2]	27	62,000
Draff			123,600
Yeast Residues			14,200
Pot Ale Syrup			51,100
Purls	5[*3]	33	
Brewers' Residues			
Brewers' Dried Grain	8.4[*4]	18.8	
Brewers' Dried Yeast	7[*4]	45.1	

*1 Pass, 1980.

*2 Borthwick of Glasgow, 1979.

*3 North of Scotland Distilling Co Ltd, 1979.

*4 National Academy of Sciences, 1974.

Many of the above materials are already marketed as animal feeds, either in their existing form, e.g. brewers' light grains, wet draff, etc, or as a more refined product, e.g. "Scotaferm", "Scotagran" and Borthwicks grain distillers' dried grains with solubles. As such, these materials no longer come into the category of "wastes" as previously and their market price is relatively high, e.g. brewers' wet draff - £25 per tonne, distillers' wet draff - £27 per tonne (March 1980), corresponding to a dry weight price in the region of £100 per tonne. It was therefore not considered worthwhile to consider distillers'/brewers' by-products as possible raw materials for the culture of other high protein foods as conversion efficiencies would require to be unrealistically high.

As feedstuffs in their own right, however, grain feedstuffs show some promise in compound pellets and are already used by some feed manufacturers as a bulk agent to allow full utilisation of the protein component of the diet. Grain by-products have been shown to have a beneficial binding effect on pellets (especially moist pellets) and may replace purpose binders to some extent. It has been suggested (Kerr and Thain, 1977) that they may also supply some useful nutrients such as vitamins and growth promoting factors.

To conclude, it would appear that grain by-products may be potentially useful in fish feeds as a direct component of pelleted diets (or conceivably as a straight wet feed for herbivorous fishes such as carp and Tilapia). Kerr and Thain suggest that fish feedstuffs may usefully contain up to 20% by weight of grain by-products, amounting to 1-2% of current UK distillery output on the basis of current UK fish feed consumption.

Due to the proven feed value of distillers'/brewers' by-products to domestic stock and the resulting high price of these materials, it is not considered feasible to use grain by-products as a substrate for the culture of other proteinaceous materials. This view is supported by indications from work in the distillery industry (Pass, 1980). Distillery residues still considered to be "waste" such as purls are generally either produced in too small a quantity or in too dilute a form to justify their recovery on economic grounds at present.

4.7 USE OF AQUATIC PLANTS

Aquatic weeds have been suggested as a possible source of feed in fish culture on a number of occasions (National Academy of Sciences, 1976; Blackburn and Sutton, 1971; Liang and Lovell, 1971; and others). Interest in this material arises primarily from the very high productivities that have been reported in comparison to land crops (see Table 4.7), from their general lack of other uses, their nuisance value which demands control in any case, and their possible beneficial combination of a fish culture system with waste water management, the production of the latter helping to defray the cost of the former.

Liang and Lovell (1976) found that *Justicia americana*, *Alternanthera philoxeroides* and *Eichornia crassipes* proved acceptable when added to diets of the channel catfish (Ictalurus punctatus). Accordingly it was decided to briefly here consider their potential usefulness in rainbow trout diets.

Data on the composition of a number of the more common and/or productive aquatic plants was obtained from the literature (Table 4.8) and incorporated in the linear programming model described in Section 2.5 in order to indicate the likely economic value of the material as a constituent of compound trout pellets. It was intended then to compare these values with estimated costs for the harvesting and processing of aquatic plants to a usable form, based on systems described by Bryant (1970), Koegal et al (1973),Lirermore et al (1971) and N.A.S. (1976). In the event,however, the very low value of these materials in trout diets as indicated by the program evaluation (Appendix H) resulting from their generally poor content of essential amino acids and especially of the sulphur-amino acids methionine and cystine, made their use appear quite unrealistic and no further effort was directed to costing, processing and harvesting techniques.

One possible exception to the above is duckweed of the genus Lemna, having a very much higher protein content than average for aquatic plants. Lemna is also rather more suitable for culture in the cooler climates where trout farming predominates than are many of the other weeds cited such as the semi-tropical Eichornia crassipes. However, unfortunately no amino acid analysis was available for this material, and its nutritive value to trout could not therefore be estimated.

While the low nutrient value and the high water content (dry matter may be only 20-30% of that for many terrestial crop plants, raising processing costs) suggests that the aquatic plants mentioned do not have a potential for direct inclusion in trout diets, it is nonetheless conceivable that the unprocessed materials could be used in the culture of aquatic trout food organisms. However, many of these plants have proved acceptable in situ as feeds for herbivorous fish species such as the grass carp and several Tilapia sp. (Little, 1979; and others), a system which has obvious economic benefits in that the cost of harvesting, transporting and processing large quantities of material for the sake of a relatively small amount of protein is avoided, and there seems little justification for the extra link involved in rearing food organisms for carnivorous species.

TABLE 4.7 REPORTED AND ESTIMATED PRODUCTIVITIES OF SELECTED CROPS AND AQUATIC PLANTS

Item	Biomass (Tons/acre)	Prod. (T/A/annum)	Crude Protein Prod. (T/A/annum)	Locality	Source/ Reference
Laminaria*1 digitata + L. longicuris (Fresh weight)	63.7	318.6		Nova Scotia	Mann, 1973
L. longicuris*1 (Fresh weight)	45.8	229		Nova Scotia	Mann, 1973
Ascophyllum*1 nododum (Fresh weight)	27.0			S. Uist	Manpower Services Commission 1977
Scenedesmus acutus (= obliquus) (Dry matter)		9.95	5.27	Dortmund	Soeder et al, 1970
S. acutus (= obliquus) (Dry matter)		21.9	11.6	Bangkok	Payer et al, 1973
S. acutus (= obliquus) (Dry matter)		19.9	10.5	Bulgaria	Vendlova, 1969
Spirulina platensis (Dry matter)			9.69	Mexico	Soeder, 1976 (after Clement et al, 1971)
Chlorella pyrenoidosa (Dry matter)			6.25	Japan	Tamiya, 1959
Chlorella Sp. (Dry matter)			2.47	Japan	Krauss, 1962
Algae (Est. theoretical yield limit) (Dry matter)		58.14			Goldman 1979

*1 All records refer to dry matter unless otherwise stated, where materials are underlined in red to avoid confusion.

TABLE 4.7 (CONT) REPORTED AND ESTIMATED PRODUCTIVITIES OF SELECTED CROPS AND AQUATIC PLANTS

Item	Biomass (Tons/acre)	Prod. (T/A/annum)	Crude Protein Prod. (T/A/annum)	Locality	Source/ Reference
Eichornia crassipes (DM)		21.22*2	4.56	USA	Boyd, 1969 1970 & 1974
Justica americana (DM)		45.2*2	10.35	USA	Boyd, 1968 & 1970
Alternanther philoxeroides (DM)		24.71*2	3.85	USA	" "
Typha latifolia (DM)		76.45*2	7.87	USA	" "
Duckweeds (Lemna Sp. DM)		7.85	2.90	Louisiana	Hillman & Culley 1978
Soybeans (Dry Seeds)		0.71	0.30	Louisiana	" "
Cottonseed (DM)		0.34	0.08	L.A.	" "
Peanuts + Skin + Hull (DM)		0.7-1.4	0.17-0.33	Georgia & Mississippi	"
Peanuts (DM)			0.19	Japan	Tamiya 1959
Alfalfa Hay (Sun Dried)		1.9-7.0	0.3-1.19	Arizona & Mississippi	Hillman & Culley 1978
Clover (DM)			0.67	Japan	Tamiya 1959
Grass (DM)			0.27	Japan	" "

*2 Boyd's figures appear to be extraordinarily high, but are unfortunately the only figures available in some cases, and are included for the sake of completeness. In some instances yields have been extrapolated from max. daily production, and all figures should perhaps be treated with caution.

TABLE 4.8 COMPOSITION AND PRICES OF AQUATIC PLANTS

	Arginine	Cystine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Tyrosine	Valine	Water	Protein	Fats and Oils	Fibre	Carbohydrate	Ash	£ per ton	Source
Chlorella (Dr.)	2.4		0.7	1.7	2.0	2.4	0.6	2.1	1.9	0.4		2.7	0.0	40.0						Krauss, 1962
Eichornia (Dr.) crassipes	1.2	0.1	0.4	1.0	1.8	1.2	0.4	1.1	1.0	-	0.8	1.2	0.0	21.5	3.6		28.2	18.0		Boyd, 1969, 74
Eichornia (Fr.) crassipes	0.08	0.01	0.03	0.07	1.12	0.08	0.03	0.07	0.07	-	0.05	0.08	93.4	1.42	0.23		1.86	1.19		
Pistia (Dry) stratiodes	0.8	0.1	0.4	0.9	1.6	1.2	0.3	1.0	0.9	-	0.7	1.1	0.0	13.1	3.7		26.1	21.1		Boyd, 1969, 74
Pistia (Fresh) stratiodes	0.07	0.01	0.04	0.08	0.14	0.11	0.03	0.09	0.08	-	0.06	0.10	91.0	1.17	0.33		2.35	1.90		
Hydrilla Sp. (Dry)	0.7	0.05	0.25	0.7	1.2	0.7	0.3	0.8	0.7	-	0.6	0.8	0.0	18.0	3.5		32.1	27.1		Boyd, 1969, 74
Hydrilla Sp. (Fresh)	0.06	-	0.02	0.06	0.10	0.06	0.02	0.06	0.06	-	0.05	0.06	92.0	1.44	0.28		2.56	2.17		
Eleocharis acicularis(Dr.)													0.0	12.5	3.6		27.9	9.9		Boyd, 1968

TABLE 4.8 (CONT) COMPOSITION AND PRICES OF AQUATIC PLANTS

	Arginine	Cystine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Tryptophan	Tyrosine	Valine	Water	Protein	Fats and Oils	Fibre	Carbohydrate	Ash	£ per ton	Source
Myriophyllum specatum (Fr.)													93.5	0.64	0.12		1.22	2.64		Boyd 68 Koegel et al 1973
Ceratophyllum Sp. (Fresh)													93.0	1.52	0.42		1.95	1.44		Boyd 1968
Alternanther(Dr philoxeroides	2.1		1.1	1.5	1.9	1.5	0.6	Trace	1.6	-	-	1.8	0.0	15.6	2.68		21.3	13.9		Boyd 1968
Lemna Sp. (Dry)													0.0	38.5	3.0	9.4		16.4		Hillman Culley 1978

CHAPTER 5

Indirect use of materials

5.1 A REVIEW OF THE LITERATURE

The culture of live food organisms as a food for farmed fish has been attempted on a number of occasions, principally in extensive culture systems, in which live food production is encouraged by manuring or fertilisation of the stock ponds, or as a first feed for the fry of delicate species. In addition to fish farming practices, the production of angling/commercial baits and of aquaria feedstuffs may also provide useful information on the culture and acceptability of live food organisms.

A wide variety of organisms are or have been cultured as baits for angling purposes, although in most cases the volumes produced are very small. In the UK two baits - maggots and earthworms - are cultured commercially on a substantial scale, while other baits predominate elsewhere (e.g. bait minnows in the USA). A number of other baits have been used by both anglers and commercial fishermen, but not generally in situations that warrant the effort involved in culture of the bait concerned, and hence descriptions in the literature of culture methods are largely lacking.

Aquarium fish culture resembles commercial fish culture in a number of ways, differing principally in scale and in the price and desired qualities of the product. As in commercial fish farming practice the majority of aquarium fish are now fed on compound dry feeds, although in flake rather than pellet form to allow for the usually much smaller size of aquarium fish. In general, however, aquarium fish tend to be kept along with other species, unlike the monoculture or oligoculture practised in commercial fish culture, such that the feed compound produced is designed to be most nearly suitable for the largest number of species. Consequently fish of quite different nutritional requirements are supplied with the same diet, which clearly cannot be optimal for all species. Live foods are therefore still commonly used as a supplementary feed to provide necessary or beneficial dietary ingredients for carnivorous fish species and fresh vegetable matter supplied for herbivorous species. The variety of live foods that are cultured for aquaria use is considerable. Among the more common kinds are included infusoria (mixed protozoans), rotifers, daphnids, gammarids, branchiopods, nematodes, enchytraeids, lumbricids, chironomid larvae, culicid larvae, dipterids, bettle larvae and some vertebrates (e.g. small live-bearing fishes such as guppies). Many other live foods are sometimes cultured but are generally more freely available from their natural habitat, e.g. *Tubifex* and *Artemia* eggs. Certain of these organisms, notably *Artemia*, are also widely used in commercial fish culture as fry feeds.

Most of the materials used for culturing live food organisms for aquaria use are far too highly priced to permit their use in commercial fish culture, unless a very high premium is acceptable for fry feeds (See Section 2.3.2), and only those organisms that may be produced on cheap or waste materials are likely to be of relevance to commercial fish culture. Nonetheless experience of live food culture by aquarists can provide an indication of the practical feasibility of culturing certain feeds.

5.1.1 The use of live feeds in commercial fish culture is here, for the sake of convenience, divided into five categories, all of which may however overlap with one another:

1) As a feed for fry reluctant to take immediately to dry or

pelleted feeds.

2) As a natural feed in an extensive culture system.

3) As a main dietary constituent.

4) As a supplementary feed to a main dry diet.

5) As a supplementary feed considered to have growth promoting properties.

5.1.2 The premium price that may be paid for fry feeds, as outlined in Section 2.3.2, permits the use of certain live diets at this stage that would be totally uneconomic were they to be used throughout the main growth phase of the fish. A number of live feeds are therefore cultured or collected from the wild for feeding to the fry of species that cannot be satisfactorily fed initially on dry compound diets, either as a result of the small or delicate nature of the fry, their inability to recognise items lacking in movement as food, or in some cases the lack of development of the enzyme system to deal with such diets (Horvarth, 1979).

Salmonid species produce relatively large fry, and rainbow trout in particular can generally be started on a dry diet soon after the yolk sac is absorbed, although trout and salmon species which refused commercially prepared diets have been started on daphnids or Artemia before being converted to dry feeds (Ghittino, 1977). As the rainbow trout is the main table fish produced in the UK there is relatively little literature produced here on the subject of live fry feeds, although a number of European trout farms are reported to use live daphnids and bloodworms in fry feeding (Masters, 1975; Hickling, 1974).

In the UK, the White Fish Authority have produced a number of reports and papers concerning the use of live diets (rotifers, Artemia and Lumbricillus) in the weaning of juvenile Dover sole, turbot and plaice on their pilot scale marine farm at Hunterston in S.W. Scotland. The Ministry of Agriculture, Fisheries and Food have done some similar work at Lowestoft. This work is summarised in the following references; Backhouse, 1979; Bromley, 1979a; Bromley, 1979b; Persoone and Sorgeloos, 1975; Sorgeloos and Persoone, 1973; White, 1978; and White, 1979. New publications on recent progress are being continually added to this list. A fledgling carp farming industry in the UK also uses small quantities of live foods in fry feeding, but has so far contributed little to the literature. Attempts have been made to do away with the need for live foods in this context, and EWOS have apparently had some recent success with a dry product, EWOS Larvstart C10, in weaning common carp fry onto the later pelleted feeds (EWOS, 1980).

Elsewhere, and particularly in Israel, the Soviet Union and Eastern Europe, considerably more work has been done on the culture and use of live foods in rearing the small fry of a variety of cyprinid, sturgeon and warm-water fish species.

Artemia larvae are widely used on account of their general acceptability, small size, high nutritional value and relatively assured supply. Some attempts have been made to culture Artemia throughout their life cycle and so to make available a fully independent source of eggs, but it has been found simpler and cheaper to exploit natural populations (Klopfenstein, D. and I., 1978). A very large number of papers have been devoted to shrimp in fish culture. Abstracts from the International Symposium on the Brine Shrimp, 1976, held by the Artemia Reference Centre, summarise much of our current knowledge and supplies much of the information used in the text.

In addition, modern Soviet experience in the use of live feeds in fish culture is summarised by Ivleva, 1969, and has been translated into English by the Israeli Service for Scientific Translations.

A potential alternative to Artemia as live food for fish fry has been suggested in small marine calanoid and harpacticoid copepods. These have received particular interest in Japan, although have been considered in the West also as first feeds for marine species with small fry. Their use is not described in detail here, but reference is made to a number of authors where additional information may be found, in particular are described by: Omori, 1973; Betouhim-El and Kahan, 1972; Corkett, 1970; Zillioux, 1969; Marshall and Orr, 1952; and Conover, 1962. Studies on the use of these copepods specifically in fish diets have been conducted by Gulbrandsen, 1979; Beck and Bergstrom, 1979; and Spinelli, 1979. The interest shown in these organisms as a fry feed in recent years springs largely from their small size rather than high productivity, and their culture is unlikely to be of much relevance to trout rearing.

Daphnia have been cultured or collected from the wild on numerous occasions as a fry feed in commercial fish culture, mainly in Europe and the Soviet Union for such species as carp and sturgeon. Their use is limited by the large size of the adult daphnids relative to Artemia nauplii and copepods, but they may be used when immature or as a weaning diet. They have also been used as a fry feed for salmon and trout in Europe (Ghittino, 1972), and as a supplementary feed (Hickling, 1974).

Daphnia are easy to culture and may be fed on a wide variety of organic wastes including animal manures.

A large number of papers have been published relating to the culture and use of Daphnia, and only a few of the more important studies are mentioned here. Culture techniques are described by Askerov, 1965; Bogotava, 1958; Briskina, 1960; Pechen', 1964; Shpet, 1950; Greve, 1968; Harvey, 1972; and Persoone and Sorgeloos, 1975. Culture techniques are also covered in a number of papers dealing primarily with the uses of Daphnia and other organisms, notably in a comprehensive review of the large-scale culture of Daphnia in sewage lagoons (Heimbuch et al, 1978) and in Ivleva's review of the mass culture of live foods (Ivleva, 1969). The use of Daphnia directly in fish culture is described by Bizyaev, 1960; Gaevskaya, 1953; Cannon, 1933; Gellis and Clark, 1935; Taub and Dollar, 1964; Vasil'eva, 1959; Dinges, 1974; McShan, Trieff and Grajcer, 1944; Ryther, 1975; Heimbuch, 1978; and Kildow, 1974.

Sometimes cultured alongside Daphnia is another small crustacean, Moina. This has received far less attention than the former, but may nonetheless provide a valuable food. Moina rectirostris may be fed to fry prior to the introduction of the larger Daphnia magna, and can be beneficial to the early survival rate of some carp fry (Horvath, 1979). The culture and use of Moina as a fry feed is described by Askerov, 1954; Askerov, 1857; and Dehn, 1955.

The only other crustaceans to have received substantial attention as live fish foods in commercial culture are the fairy shrimps Eubranchipus and Streptocephalus. Use of the latter is at present largely confined to the Soviet Union and Eastern Europe. Culture techniques are described by Chabdarova, 1956; and Novikova, 1958; and nutritional value by Karzinkin, 1953. Eubranchipus is confined to America and has received very much less attention but is considered briefly by Bond, 1959.

Several small species of annellid worms have achieved some use as fry feeds in commercial fish culture, principally *Enchytraeus albidus* (white worm), *Tubifex* sp. and *Lumbricillus* sp. Only *Enchytraeus albidus* is widely cultured, both *Tubifex* and *Lumbricillus* being obtained from natural populations in the small quantities in which they are used.

E. albidus is very simple to culture but, in common with most other fry diets, is generally cultured on high quality substrates (yeasts, wheat flour, etc) which would make its use as a main growth feed prohibitively expensive. Nonetheless, *E. albidus* has been cultured on a wide range of other materials, including manures, spent grains and crop residues. Culture techniques for *E. albidus* are described by Ivleva, 1954, and their use in fish culture by Karzinkin, 1953; Golovanenko, 1962; L'vov, 1948; Malikova, 1956; Petrenko, 1951; and Protasov, 1948. A useful summary of Soviet experience of *E. albidus* is provided in English by Ivleva, 1969. The main English language work dealing with the culture of this organism is a review produced by Galtsoff and Needham, 1959.

Tubifex sp. have found very occasional use in fry feeding, but are better known from their use as an aquaria feed. The similar small marine worm *Lumbricillus rivalis* on the other hand has been found to provide a good weaning feed for larval flatfish, being used by the White Fish Authority in their Dover sole diets at Hunterston (W.F.A., 1977a).

A small number of nematods species, *Turbatrix aceti*, *T. ludwigii* and *T. silusiae*, collectively known as micro-worms, have on occasion been used as fry feeds. A similar species, *Panagrellus recidivivus*, has been cultured on a larger scale at a number of fish hatcheries (Bruum 1949; Bennike, 1941; Knaack, 1958; White, 1959;

and Morton and Cook, 1966).

The foregoing groups include most of the organisms commonly grown as live feeds for fry diets in commercial temperate fish culture. A number of others are in occasional use, as might be expected. Chironomid larvae appear to be achieving increasing usage in Europe and America (Horvath, 1979), although the principal interest in these organisms has concerned their importance as a supplementary feed or as a natural feed in extensive culture systems. A number of other live foods have been used on occasion as feed supplements or attractants, but not specifically with regard to fry rearing.

5.1.3 Live foods are generally the primary or only food source in extensive culture systems, being produced naturally along with the fish in the culture environment. Literature relating to this aspect of live feeds therefore concerns itself mainly with the various means available to enhance the natural productivity of the useful part of the fish population, which may be achieved by:

1) Increasing the primary and hence also secondary productivity of the environment by optimising conditions for plant growth, usually by fertilisation with mineral fertilisers or manure.
2) Introducing new species of food organism where the immigrant species is judged to be more useful as a fish food than are native organisms.
3) Attempting to control primary and secondary production by means of environmental control, such that those organisms regarded as useful in providing forage for the fish are favoured at the expense of less useful, competing items.

Of these three categories, fertilisation and/or manuring is the most common in general fish culture but is little used for trout on account of the latter's high oxygen demand and low nitrogen/carbon dioxide tolerance. Many wide ranging reviews of this means of increasing productivity have been produced, and the following provide comprehensive accounts; Schaperclaus, 1933; Mortimer and Hickling, 1954; Wohlfarth, 1978; Hepher and Schroeder, 1977; and Kildow, 1974. Israel is particularly active in the field of raising productivity by manuring, and recent work is frequently reviewed in "Bamidgeh".

Management of the environment to favour desirable species has been rather more widely used in trout fisheries and may take the form of either encouraging favoured food items by judicious planting and provision of breeding grounds or of encouraging trout at the expense of coarse fish competitors and predators. Fishery management of this nature is summarised in many of the standard textbooks, particularly; Schaperclaus, 1933; Hickling, 1974; Huet, 1972; Seymour (undated). Manuring and fertilisation of water bodies also may affect the species mix to a large extent, such that these two methods of optimising useful production may overlap to some extent.

The introduction of non-indigenous species to new environments to replace less useful species is not much practised in the West but has received a good deal of attention in the USSR on account of the very great distances and faunal variation occurring within the one country and facilitating introduction. Much of the recent Soviet experience in this field is summarised by Zhuravel', 1969, and Ivanov, 1972.

In Europe, the relatively small geographical areas occupied by most individual countries add to the problems of transport with a multitude of differing legislation. Nonetheless the wide faunal variation between Europe and the New World might encourage investigations of this kind in the future.

5.1.4 Live feeds have nearly always been of secondary importance in intensive trout culture (Halver, 1972). One possible exception to this is in the use of silkworm pupae in Japan, China and Russia, which has been described by Hashimoto and Okaichi, (1965) and Hikada (1966) but which appears to be becoming increasingly insignificant in the face of the rapid expansion of the Japanese fish culture industry while the supply of pupae remains relatively stable (Nomura and Fuji, 1968).

Few other organisms have been considered as a major dietary ingredient in intensive fish culture. Larvae of the beetle *Tenebrio molitor* and of the fly *Calliphora erythrocephalus* have been fed to eels on an experimental basis, producing good conversion figures in the region of 3/1 wet weight (Deelder, 1978). Larvae of the housefly *Musca domestica* have also attracted some attention as a potential feedstuff since an interest expressed by Lindner (1919) although much of the work has concerned their value as a food for poultry (Calvert, Morgan and Eby, 1971; Calvert, Martin and Morgan, 1969). A more recent study has used fly larvae in salmonid feeds, but as a dry constituent of a compound diet rather than as a live feed. (Spinelli, Mahnken and Steinberg, 1979).

While the use of whole live foods avoids the expense of processing, nonetheless the high protein content of most live food items may often be more economically utilised when compounded with a lower protein or vegetable component.

5.1.5 A wide variety of live feeds have been used in trout culture to supplement prepared diets. Being in general considerably more expensive than the basal ration, live feeds should however only be used when the expected benefits outweight the increased cost.

Live foods have been known to encourage a feeding response in lethargic fish, and may thus facilitate in some cases a return to good condition. There is also the possibility that the addition of certain kinds of live food items may supply essential ingredients (minerals, amino acids, vitamins, etc) lacking in the normal ration, resulting in better health and faster growth and acting essentially as growth promoting agents. Conversely, under semi-intensive conditions the natural diet is high in animal proteins and so the supplementary feed may be low in this, designed to supply an adequate total diet at least cost (Gurreda, 1968; Szumiec, 1968; Hepher, 1979).

Daphnia and chironomid larvae have both been used as supplementary feeds, and claims have been made that these organisms may promote growth to a degree exceeding their known nutritional contribution when fed to carp (Yashouv, 1956; McLarney et al, 1977), mullet (Yashouv and Ben Shachar, 1967) Yashouv, 1970), sturgeon (Konstantinov, 1952), and _Tilapia_ (McLarney et al, 1977). According to Masters (1975) chironomid larvae collected from the wild are used in large numbers of European fish farms, as a fry feed and as a supplementary feed, while in other cases they are cultured in conjunction with _Daphnia_ (Hickling, 1974). Cultivation of daphnids and of bloodworm larvae has been described by Wirshubsky and Elchuness, 1952; Yashouv, 1970; Sadler, 1935; McLarney, Henderson and Sherman, 1974; and Konstantinov, 1953 and 1955. Ivleva (1969) has reviewed much of the Soviet Union's experience of live supplementary feeds, and cites a number of references detailing culture methods for these organisms.

In Japan, Gammarus sp.and Lema flavius have both been used as supplementary feeds in carp culture (Anon, 1952) but this practice would not appear to be widespread. Laboratory scale culture of Gammarus is described by Sexton 1928, and their biology and growth by Monk, 1976.

Earthworms have been used as attractants in eel diets (Hallows, 1980) and shellfish offals have been used to play a similar role in flatfish diets in the UK in recent years, but in both cases the material is minced and fed in a moist pelleted or paste diet rather than being used whole/live.

A final method of supplementing a basal diet with live foods is to site lights near to the pond at night in order to attract flying insects (Hickling, 1974). This method is apparently still used occasionally in Japan, although quantities involved are probably not very great.

5.1.6 The composition of potential live foods is not well documented, but is partially reviewed in a comparatively small number of papers; Yurkowski and Tabachek, 1979; Watanabe, Arakawa, Kitajima, Fukusho and Fujita, 1978; and Malikova, 1956. Incomplete analyses of a number of live foods are recorded by Ivleva (1969). The composition of particular food items, such as worms (Lawrence and Millar, 1945; Sabine, 1978) and maggots (Calvert, Morgan and Eby, 1971) is comparatively well researched.

The productivity of cultured invertebrates is recorded in a wide range of papers, and a major problem is involved in reducing these to a common basis for comparison purposes. A number of the a number of references detailing culture methods for these organisms.

In Japan, Gammarus sp.and Lema flavius have both been used as supplementary feeds in carp culture (Anon, 1952) but this practice would not appear to be widespread. Laboratory scale culture of Gammarus is described by Sexton 1928, and their biology and growth by Monk, 1976.

Earthworms have been used as attractants in eel diets (Hallows, 1980) and shellfish offals have been used to play a similar role in flatfish diets in the UK in recent years, but in both cases the material is minced and fed in a moist pelleted or paste diet rather than being used whole/live.

A final method of supplementing a basal diet with live foods is to site lights near to the pond at night in order to attract flying insects (Hickling, 1974). This method is apparently still used occasionally in Japan, although quantities involved are probably not very great.

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TABLE 5.1 RECORDED PRODUCTION LEVELS FOR LIVE FOODS

Food Item	Peak Biomass	Daily Production	Feed Used	Reference
Enchytraeus albidus	35,000g/m^3	2,800g/m^3	Not Recorded	Ivleva, 1955
Enchytraeus albidus	340g/m^2	70g/m^2	Not Recorded	Ivleva, 1969
Eisenia foetida/ Lumbricus rubellus	Not Recorded	110g/m^2	Animal Manures	Gaddie & Douglas
Panagrellus redivivus	670g/m^2	75g/m^2	Oat groats	Ivleva, 1969
Musca domestica (larvae)		4,000/m^3 (As grown in layers 5 cms. deep Approx.to 200g/m^2)	Chicken Manure	Calvert, Morgan and Eby, 1971
Mosquito (larvae) (Culex sp.)		30g/m^2	Dry Corn	Masters, 1975
Chironomids (larvae)	15,000g/m^3	250g/m^3	Not Recorded	Konstantinov, 1957
Chironomids (larvae)	Not Recorded	25g/m^2 (500g/m^2 of flour if stacked in trays)	Proteolysed Yeast	Ivleva, 1969
Chironomids (larvae)		40-50g/m^2	Manures	Yashouv, 1970
Chironomids + Daphia		20g/m^2	Manures	Hickling, 1974 Buschkiel
Daphnia	1,800g/m^3	100g/m^3	Not Recorded	Gaevskaya 1945
Daphnia	610g/m^3	40g/m^3	Horse Manure	Shpet, 1950 Askerov
Daphnia	250g/m^3	25g/m^3	Horse Manure	Meshkova 1957
Daphnia	800-1,200g/m^3	30-50g/m^3	Proteolysed Yeast	Briskina, 1960, 1956
Daphnia		25-40g/m^3	Mineral Fertilisers	Askerov, 1958, 1960

TABLE 5.2 RECORDED CONVERSION FIGURES FOR LIVE FOODS

Food Item	Feed Used	Conversion	Reference
Enchytraeus albidus	Meal	4.5/1	Ivleva, 1961
Enchytraeus albidus	Bran	2/1	Ivleva, 1961
Enchytraeus albidus	Potato	3/1	Ivleva, 1961
Enchytraeus albidus	Bread	2/1	Ivleva, 1961
Lumbricus terrestris	Cattle Manure:		
	Wet	10/1)	Spedding, 1975
	Dried	2/1)	
Eisenia foetida/ Lumbricus rubellus	Pig Manure:		
	Wet	6-7/1	Tacon, 1980 (P.C.)
Musca domestica (larvae)	Chicken Manure:		
	Wet	30/1	Calvert, Morgan and Eby, 1971; Miller and Shaw, 1969
Panagrellus redivivus	Oat Groats	1.8/1	Ivleva, 1969
	Oat Meal	3.6/1	Ivleva, 1969
	Barley Meal	14.5/1	Ivleva, 1969
Daphnia Sp.	Horse Manure	0.25/1*	Meshkova, 1957
Daphnia Sp.	Proteolysed Yeast	0.05/1*	Briskina et al, 1960; Briskina, 1957

* Presumed to be consuming primary production of algae in low intensity systems.

TABLE 5.3 POTENTIAL AVAILABILITY OF ORGANIC WASTES

Material	UK ('000 Tons)	Scotland ('000 Tons)	% Dry Matter	Reference
Cattle Manure	163,000		10-20	1
Cattle Manure	102,000		10-20	2
Cattle Manure		30,000	10-20	3
Pig Manure	17,000		10-15	1
Pig Manure	11,600		10-15	2
Pig Manure		750	10-15	4
Poultry Manure	7,000		25-35	1
Poultry Manure	6,800		25-35	2
Poultry Manure		750	25-35	5
Sheep Manure	9,800		15	2
Sheep Manure		2,500	15	6
Trout Manure	100		10	7
Domestic Sewage	50,000		10	2
Domestic Sewage	1,600		100	8
Cereal Straw	9,000			9
Sugar-beet Tops	6,000			9
Peavining Residues	2,300			9
Other Crop Residues (sprout, tomato, hop and potato residues - inedible parts of plants)	2,300			9
Wood Residues	210		High	10

SOURCES FOR TABLE 5.3

1. Raymond, W. F., 1977. "Farm Wastes". Biologist, 24. 80-85.

2. Wheeler, R. P., 1979. "Waste Disposal and Agriculture; Treatment and Disposal of Farm Wastes". Royal Soc. of Hlth. Jnl. Vol. 99, pp 143-151.

3. Estimated from figures for number of beasts in Scotland (from Agricultural Statistics, U.K., 1975) and manure production per beast (from Spedding, 1975).

4. Estimated from figures for number of beasts in Scotland (from Agricultural Statistics, U.K., 1975) and manure production per beast (from Thornton, 1980). Personal Communication.

5. Estimated from figures for number of birds in Scotland (from Agricultural Statistics, U.K., 1975) and manure production per bird (from M.A.F.F., Advisory leaflet 320, "Poultry Manure").

6. Estimated from figures for number of beasts in Scotland as proportion of number of beasts in U.K. (from Agricultural Statistics, U.K., 1975).

7. Estimated assuming U.K. production of 5,000 tons reared on dry compound diets.

8. Tacon, A. J. G., 1978. In: Conference on fishfarming and wastes, 4-5 January, 1978, London. Ed. C. M. R. Pastakia. Organised by the Institute of Fisheries Management and the Society of Chemical Industry.

9. Environmental Resources Ltd., 1976.

10. Scottish Forestry Commission, 1978. Personal Communication.

TABLE 5.4 PROTEIN CONTENT OF ANIMAL MANURES AND SEWAGE SLUDGES

Material		Moisture %	Protein %		Source/Reference
			True	Crude	
Poultry Manure:	Fresh Faeces	70	3.2	0.9	1, 2, 3
	Deep Litter Manure	32		20.5	1, 2
	Broiler Manure	32		27	1, 2
	Dried Poultry Manure	12	14	32	1, 2, 3
Pig Manure:	Fresh Faeces				
	Slurry				
Cattle Manure:	Fresh	80-90			
	Dried	10		9.4	4
Sheep Manure:	Fresh				
	Dried				
Horse Manure:	Fresh				
	Dried	10		9.8	4
Sewage:	Primary Sludge				
	Activated Sludge (Settled)	99	0.34	0.41	5
	Activated Sludge (Dried)	7.85	31.25	37.8	5

records available are summarised in Tables 5.1 and 5.2. Ivleva (1969) contains further records which have not been included due to their methods of measurement precluding comparison. A comprehensive treatment of specific production of aquatic invertebrates is provided by Zaika (undated) but is of academic interest rather than practical interest to would-be culturists.

5.2 ORGANIC WASTES IN THE UK WITH POTENTIAL FOR THE CULTURE OF TROUT FOODS

Organic wastes suitable for direct inclusion in trout feeds are numerous and may be used even when available in relatively small quantities. Those organic wastes which would require to be converted into useful food via an intermediate organic culture would however require to be available in very much larger quantities to allow for the inefficiency of conversion and to make the operation worthwhile. Organic wastes available on a suitable scale fall broadly into two categories - sewage sludges and manures and agricultural crop residues. The potential quantities of these materials available in Scotland and the UK are summarised in Table 5.3.

5.3 CULTURE OF EARTHWORMS

5.3.1 In Britain earthworm culture is a fairly recent business with only a few commercial growers, and the total UK production is currently thought to amount to less than 600 tons per annum (Penhros

Barn Products, 1981) compared with an annual production in the USA believed to be in the region of 15,000 tons (Douglas and Gaddie, undated). At present the main market is as an angling bait, and should it prove viable to culture earthworms as a high protein feedstuff for agricultural purposes then the market could expand very considerably.

While a number of worm species have been cultured at one time or another, the bulk of the UK production comprises the following three species:

Eisenia foetidus	-	manure worm or brandling
Lumbricus rubellus	-	red worm or garden worm
Lumbricus terrestris	-	lob worm

These worms have been chosen according to their ability to meet the demands of the bait industry, and may not be the best for production of a protein feedstuff. Eisenia foetidus in particular contains a substance disagreeable to certain animals, and some fish are found to reject this species. It is also possible that it would prove harmful to the fish were it to be accepted in large quantities.

Lumbricus terrestris, on the other hand, is highly acceptable to virtually all fish large enough to take it, and can be fed in large quantities without apparent ill effects. While Lumbricus terrestris can be grown on animal manures it does not appear to adapt well to culture conditions, growing and reproducing comparatively slowly and being intolerant of the high stocking densities that are found suitable for both Lumbricus rebellus and Eisenia foetidus.

Lumbricus rubellus fetches a lower price as a bait worm than L. terrestris on account of its smaller size and resulting inferior quality but is nonetheless probably the most widely cultured species of earthworm in Britain due to its rapid growth and reproduction rate and the very high densities at which it can be kept. For the production of a protein feedstuff it is almost certainly the most suitable of the three species considered, requiring little attention and being as cheap to produce as E. foetidus but lacking the latter's unpleasant flavours and deleterious substances. Its relatively small size (2"-3"), while limiting its value as bait, need not be a drawback for feeding to trout and might indeed be considered a positive advantage in that it may be fed whole to smaller fish than could be the case with L. terrestris. Throughout the rest of this section, therefore, it is L. rubellus that is being considered unless specifically stated to the contrary. In most ways the culture of the three species is essentially similar.

5.3.2 Methods of culturing earthworms vary greatly in their complexity, from simple unenclosed outdoor beds to stacked indoor trays with automatic heating and watering systems. The basic requirement is for some form of container in which the worms and their food can be placed and from which they may be periodically removed.

The depth of the bed is of some importance, determining to a large extent the production per unit area. Indoor tray cultures are frequently of a depth of no more than 6" to facilitate handling, whereas bed and field cultures may be several feet deep, the limiting factor being the lack of oxygen and the harmful anaerobic conditions arising at greater depths depending on the nature of the culture medium, the degree of saturation, the frequency with which the bed is turned and the stocking density of the worms.

A number of organic and particulate materials will serve as an earthworm culture medium, the essential feature being that the material should contain sufficient organic matter to permit good growth in the worm. Among the materials in common use may be included animal manures, waste paper, cardboard boxes, sewage sludge, well rotted sawdust, peat moss, leaf mould, grass clippings, leaves and kitchen wastes. Frequently other materials such as peat moss, sand and vermiculite are added to improve the consistency and to allow oxygen to penetrate to a greater depth. When properly prepared, the medium should ideally have the following properties:

- it should remain porous and resist packing
- it should retain moisture adequately
- it should have a pH value of between 6.0 and 7.5
- it should be high in organic matter in a form available to earthworms as food.

For the large scale culture of worms as a low-priced protein feed (as opposed to a high-priced bait) the material should also be cheap. Animal manures are generally regarded as being the best materials available at low cost for providing feed for earthworms. A large number of such manures have been used in the past, although dairy manure and rabbit manure are considered most suitable. For mass production it is essential that whatever material is chosen should be available in large quantities and on a fairly regular basis. While rabbit manure has proved highly satisfactory for the production of bait worms on a comparatively small scale, it is highly unlikely to be available in sufficient quantities for the much larger scale of production of worms envisaged here. Trout excreta could in theory also be used to grow earthworms, but the expense of de-watering this material would make it an unattractive proposition. In addition it would require more frequent clearing of the ponds than is at present usually the case (except where "self-cleaning" tanks and ponds are used), since the food value of the material is clearly liable to decline after a period as the organic materials become utilised by other organisms.

Of the various manures, only three are likely to be available in the quantities and at the price required: cattle manure, pig manure and poultry manure (Table 5.3). Cattle manure is found to be highly satisfactory for the purpose, whereas pig manure is usually available in the form of a slurry, increasing the problems and the cost of transportation, and is a rather offensive material to work with. It is moreover not regarded as being a particularly good feed for worms, although recently Rothampstead experimental station has achieved good results using this material (Agricultural Research Council, 1981). Poultry manure also is not generally regarded as being particularly satisfactory on account of its high nitrogen and phosphoric acid content, both of which are harmful in quantity. On the other hand, its suitability may be enhanced by liming, aging and leaching, and its availability in large quantities and at low cost may outweigh its disadvantages. The protein contents of the main manures used are shown in Table 5.4.

Techniques of worm culture are fully described in a number of manuals on the subject, and those requiring further information on this aspect are referred to Douglas and Gaddie, 1975; Denham, 1977; Gaisford, 1977; and Edwards and Lofty, 1972. Briefly, manures are leached to remove salts and are then mixed with the texturising material, and the prepared medium added to the culture beds. Having stocked the bed with the intended species of worm, the degree of attention and work bestowed depends very much on the individual grower and the intensity of the operation. The simplest technique is to leave the bed with perhaps occasional watering only for the required period of time (3-8 months, according to temperature, food quality and quantity and the species under cultivation), after which they are harvested and sold. To obtain the maximum production from a given area of beds however considerably more attention is required, adding supplementary food at intervals, maintaining the moisture content and pH at optimum levels and possibly aerating the beds by turning or other means. There is also some evidence to suggest that continual harvesting of the beds could produce a higher overall yield per unit area than the more usual method of harvesting the beds at relatively long intervals.

Harvesting the worms, as currently practised, consists of removing all the soil/medium from the bed layer by layer and placing it on a sorting table such that the soil from the bottom of the culture bed is at the top of the pile on the table. This earth from the top of the pile is then carefully raked away and, containing most of the egg capsules, is returned to the culture bed along with a new supply of culture medium. The raking process is then continued under a bright light, and as the surface layers are removed the worms move away from the light towards the centre of the pile, until eventually nearly all the earth has been removed and a mass of worms is left, the worms then being sorted, packed and sold. It should be emphasised however that this technique refers to raising worms for a highly priced bait market, and in order to produce worms cheaply enough to be used as a feedstuff would necessitate very considerable reductions in cost.

5.3.3 The price of worms as advertised in the angling press as at January 1980 is in the region of £1.10 per hundred for red worms (*L. rubellus*) and £3.50 per hundred for lobworms (*L. terrestris*). These prices correspond to £1-£2 per pound weight. These are retail prices, and are considerably in excess of wholesale prices where these are applicable. These very high prices result from a combination of the very small scale of culture, low levels of competition, and the high price of alternative baits failing to exert pressure on the producers. The value of worms as a feed to the fish farming industry is naturally very much less than the price accepted by the bait industry.

There are four principal strategies which might be adopted in the utilisation of earthworms as a trout feed:

1) Worms could be fed whole to trout as the sole diet.
2) Worms could be dried and processed into meal and incorporated in the formulation of compound pelleted feeds, or minced and incorporated in moist pelleted diets.
3) Worms could be fed whole as a substantial part of the total diet in conjunction with low protein compound pelleted feeds in a proportion such that the trout still received the minimum nutritional requirements.
4) Worms could be fed to the trout as a dietary supplement, constituting a small or negligible part of the diet by weight but having a tonic value.

The value of earthworms to a fish culturist will depend on the best use to which the worms may be put. Unfortunately there is relatively little experimental data available on the growth of trout resulting from feeding with earthworms.

Worms (L. rubellus) fed to trout in small scale trials conducted by the author gave conversion ratios in the region of 7/1 (Table 2.1.). This is much as might have been expected from the protein content of fresh worms of around 12% (Appendix D). Feeding trials at Rothampstead experimental station have apparently produced better growth and conversion efficiencies than compound pellets (Tacon, 1981), although it is probable that these figures are referring to dry weights of worms.

In order that the feed cost of producing a given weight of trout using worms should not exceed the feed cost of producing the same weight of trout using conventional compound feeds, it is necessary that:

$$\text{Cost per ton of worms} \times \text{Conversion factor worms/trout} \leqslant \text{Cost per ton of compound feed} \times \text{Conversion factor compound/trout}$$

Pelleted feeds for growing trout are generally priced in the region of £250-£350 per ton, with associated conversion ratios of between 1.5/1 and 2.3/1. The higher priced feeds frequently give the lower conversion ratio and vice versa, such that the cost of feed in producing 1 ton of rainbow trout is usually in the region of £500-£550 (See Chapter 2). This figure is closely corroborated by estimates received from practising trout farmers.

Substituting these figures into the above equation:

$$\text{Cost per ton of worms} \ \ X\ 7.0 \ \ (£250\text{-}£350)X(2.3\text{-}1.5) \leqslant £500\text{-}£550$$

Therefore:

$$\text{Cost per ton of worms} \leqslant £75.$$

It should be noted that this is the maximum theoretical value of earthworms as a feedstuff in trout culture using worms as the sole diet. In general the value will be further reduced on account of the associated costs of feeding - preparation, greater bulk for transport, handling and storage, etc. Worms can be fed to trout as the sole diet for substantial periods, but it is not known if this may be continued indefinitely without any dietary disorders arising. This is currently believed to be receiving some attention from Dr. Albert Tacon. Worms appear to be nutritionally adequate in all major dietary ingredients (Appendix D).

The feeding of whole worms would require modifications to much existing equipment and especially to automatic feeders where these are in use. For this reason it is unlikely that a trout farmer could be persuaded to switch from pelleted feeds to live feeds unless substantial savings could be expected.

The second feeding strategy envisaged - that of including worm meal in a compound pelleted feed - offers several advantages; the high protein content of the worms could be padded out with cheaper low grade protein materials without detracting from the overall nutritional adequacy of the diet; the use of worms in meal form would considerably relieve difficulties of storage, handling and transport; and the incorporation of the material in pelleted form would avoid the need to modify existing apparatus.

The value of worms as an ingredient of compound pelleted feeds has been estimated by linear programming methods, although the value found will depend to some extent on the prices and quantities available of the other raw materials included in the linear programming analysis, based on a nutrient analysis conducted on behalf of the author by Dr. Ambler of the Department of Molecular Biology of Edinburgh University. Assuming 90% digestibility, the maximum price at which it would be profitable to incorporate earthworm meal in a compound pelleted diet would be in the region of £230 per ton (Appendix H), corresponding to a price of £65 per ton of fresh worms. At this price, earthworm meal could be incorporated in the pelleted diet at levels of around 4% by weight of the total. This could represent a very considerable size of market potential for earthworm meal in Britain, corresponding to approximately 400 tons of earthworm meal per annum. At lower prices, the proportion of eathworm meal in the optimal (least cost) diet approaches 100%, being prevented from attaining this figure only by the requirements for vitamin additives built into the analysis model.

The reduction of worms to meal would however add considerably to the cost of this material. It is likely that this would cost a minimum of £30 per ton of raw material, similar to fish meal (See Section 3.4), thus reducing the value of worms (wet weight) to no more than £35 per ton. One way round this would be to include worms in a moist pelleted diet, a possibility considered further in Chapter 6.

The third feeding strategy considered - that of feeding worms in conjunction with low protein pelleted diets - depends upon the worms having higher levels of essential amino acids than are required by the trout, such that the excess could compensate to some extent for relatively cheap low protein compound pellets deficient in these amino acids. This mixture of a wet and a dry compound diet would necessarily add to the complications of the feeding routine. However, by complementing cheap low protein pellets with high protein worm meal, the value of the worm meal might be raised above the value of standard pellets to the extent that the combined diet remains no more expensive than a diet of standard pellets alone.

The fourth strategy - that of feeding small quantities of worms as a supplement to the diet - needs further experimental evidence before it can be properly evaluated. There is some evidence to suggest that the addition of small amounts of live food, e.g. chironomids and Daphnia, notably increases the growth of carp fed on a standard diet, although the actual weight of live food given is itself so small that the increase in the growth rate of the fish observed could not be attributed to the nutritive value of these animals, and that they must therefore supply some element, not necessarily chemical, in which prepared foods are lacking or at least deficient. If this could be shown to be true also of trout fed small quantities of live food, then the price commanded by the small quantities of live food required could be very much higher than the price paid for the very much larger quantities of compound pelleted feed used as the staple diet. There is limited experimental evidence relating to the effect of live food supplements on trout growth, such that it would not be possible to evaluate the use of earthworms in this fashion except on the basis of stated assumptions (See Appendix L). Worms fed to trout as a supplement to a pelleted diet by the author did appear to increase the trouts' appetites with respect to the control group, but the trial was not of sufficient size to be in any way statistically sound. A repeat experiment on a larger scale might be of value.

5.3.4 The ability to culture worms at a cost enabling their use in the low priced feed industry will depend on very substantial savings being made in nearly all areas of production costs. Economies of scale and technological improvements, especially increased mechanisation, may go some way towards achieving this.

The major costs associated with the production of bait worms may be broadly categorised as follows:

Buildings and Materials

Feed

Heating and Lighting

Machinery and Equipment

Labour (excluding sorting and packing)

Packing and Sorting

At present the high price received for bait worms makes it worthwhile to increase the yield, especially where production is confined to relatively small areas, by expensive methods such as heating indoor beds or by supplementing their diet with superior quality feeds, such as grain meals. Many of these practices would be untenable if it were desired to produce worms at a price permitting their use as feedstuffs. From enquiries among the small number of worm producers currently operating in the UK it is clear that methods adopted vary tremendously, particularly with respect to the balance between capital intensive and labour intensive systems. It would be necessary to reduce costs over the whole range, but particularly as regards labour costs, in order to produce worms at a cost compatible with their use in trout feeds.

5.3.5 By raising production to a scale more in line with feedstuff requirements, considerable economies of scale may be achieved in most areas.

Native species of earthworm may be raised out of doors for most of the year, although production is extremely low or negative during the winter months when the trout culturist's requirements are also low. Open field cultures are therefore suitable provided precautions, in the form of boundary barriers and covering nets, are taken against the major worm predators such as moles, shrews and birds, thus greatly reducing costs of buildings and materials and eliminating heating and lighting costs.

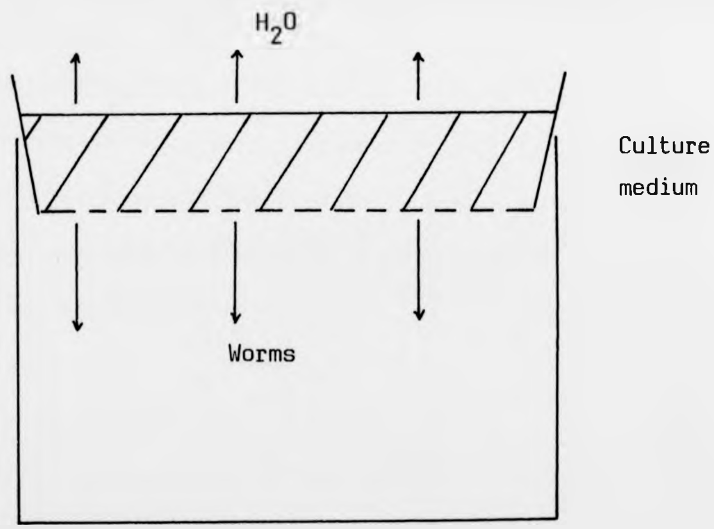
Feed costs appear to be incapable of further substantial reduction, but by using manure at approximately £2 per ton, these are already well within acceptable limits. Sorting and packing, a major expense in the production of worms for bait, are largely unnecessary for their use as feed.

Labour remains the major problem. In order to produce earthworms at a cost near to or below the target of £70 per ton (their estimated value as a feedstuff), then further very substantial savings in labour costs are required. These can only realistically be achieved by mechanisation of the labour-intensive operations - spreading the feed (manure), watering the beds and harvesting the yield. Spreading the manure and watering the beds (the need for which would be much reduced out of doors) would cause few problems and could be carried out by existing agricultural machinery. Mechanised methods of harvesting the worms are rather more speculative. Three possible methods of harvesting worms on a large scale are envisaged.

The first proposal is that the worms might be removed from the culture medium using a large mechanical sieve. The efficiency of this would depend to a large extent on the friability of the culture medium, which would probably not be high for a rich organic soil of sufficient moisture content for the culture of worms. It is also quite probable that the sieve would mechanically damage the worms, greatly reducing their storage properties if intended to be kept live prior to use.

A second proposal similarly makes use of a large sieve, but relies on a dessication avoidance reaction of the worms to move through the mesh and to drop into an enclosed container below from where they may be removed for use (Fig. 5.1)

Fig. 5.1.



A similar method is used by commercial maggot producers to separate maggots from the spent culture medium, but in this latter case the medium is spread thinly and the process is very much faster, relying on a negative phototropic reaction rather than on drying of the surface layers. The drying method works fairly well for worms on a small scale, but would probably require to be speeded up, perhaps by reverse ventilation, for use on a larger scale. Both of the above systems would be fed by a mechanical digger of the JCB kind.

The third proposed method of separation relies on worm "migration", the propensity of worms to crawl on the surface under conditions of moisture and darkness. By placing deep containers sunk into the ground such that the top is level with the ground surface it is possible under some circumstances to collect large numbers of worms, although it is noticeable that numbers collected are frequently greater when the container contains a poisonous solution, indicating that normally only a part of the yield is retained. By adjusting the spacing of these collectors within the culture area, it should be possible to select an arrangement that produces a harvest close to the maximum sustainable yield. While this method offers certain attractions relating to its cheapness and simplicity of use, daily yields would be subject to extreme variations and some means of evening this out, possibly by storing or returning excess yields, would probably be required before this could prove to be a workable system.

On the basis of the foregoing, a very tentative estimate of the likely minimum cost of production (1981 prices) of worms as a feedstuff may be made, based on an annual output of 1,000 tons (fresh weight).

Land requirement

Maximum yield	= 90 lbs per sq. yd. p.a.
Likely maximum outdoor yield	= 50 lbs per sq. yd. p.a.

(Yield would be reduced due to unfavourable growth conditions for much of the year, but could probably be partially compensated by increasing the culture depth to 3ft or more rather than approximately 2ft as used in the quoted indoor system).

Area required to produce 1,000 tons = 45,000 sq. yds.
= 9 acres

Cost of land rental or opportunity Cost at £100 per acre = £900 p.a.
(This would be expected to vary extensively depending on situation and land quality).

Machinery requirement

Machinery required to feed self-operating riddles, capable of shifting 45,000 cubic yards or approximately 90,000 tons of soil per year, or up to 300 tons per day. 2 JCB's at £18,000 each, depreciated over 6 years = £6,000

20 self-operating (surface drying) movable riddles to hold 50 tons each at depths of less than 1 yd. to allow

sufficiently rapid drying over 10 days - 1 fed by each mechanical shovel per day. Estimated at £600 each, depreciated over 6 years = £2,000

Labour requirement

2 shovel operators/general labourers at £6,000 p.a.	= £12,000
1 supervisor at £7,000 p.a.	= £7,000

Feed requirement

10,000 tons of manure at £2 per ton	= £20,000
Total Cost	= £48,000
Cost per ton	= £48

On the basis of this estimate, it would appear that it may be possible to produce worms within the target cost of £60-£70 per ton, although it must be admitted that the suggested costs, particularly with regard to machinery, and highly uncertain.

Rothampstead experimental station, assisted by the National Institute of Agricultural Engineering, the National Institute for Research in Dairying and the Poultry Research Centre, has recently conducted considerable research into the large scale production of Eisenia foetida on manures and vegetable wastes, although details relating to their culture techniques do not appear to have yet been published.

5.3.6 A number of other factors must be borne in mind in any consideration of the potential of earthworms as a feeding stuff.

Transport, when necessary, would be particularly costly since a very much greater wet weight of worms would be required to replace a given weight of compound pellets, and the weight of manure required to feed the worms would be multiplied again by the relevant conversion factor. In the foregoing costed hypothetical example it is therefore assumed that the worms are cultured "on site" at the trout farm and close also to a regular supply of manure, e.g. from an intensive livestock unit.

Storage space requirements would similarly be relatively larger than for the equivalent dry feeds, although where worms are cultured on site there would be no need to store worms other than as a reservoir supply to even out fluctuations in yield. Earthworms may be kept in good condition in damp moss for relatively long periods, or as solid masses for shorter periods provided they are kept cool. Should it prove necessary to store worms for longer periods they may be satisfactorily frozen or reduced to meal, although both these processes incur appreciable extra expense as outlined in Sections 3.1-3.4.

Pollution aspects of supplying earthworms to fish ponds are uncertain. In general, minced wet feeds and moist pellets pollute more than dry compound pellets (Davies, 1979), although it is probable that whole worms would offend less in this way than would minced feeds.

Contamination, either with pathogens or with heavy metals, has proved to be a controversial topic with regard to all manure and sewage based systems. Recent studies (Ireland, 1977) have demonstrated that some species of earthworm can accumulate large concentrations of lead without obvious damage to themselves, the lead being held in non-toxic form within certain of the cells. Lumbricus rubellus has been shown to possess this faculty where it occurs in acidic high-lead soils. Clearly this has implications for their use as fish fodder, although this is much more likely to be a problem where it is intended to use sewage sludges instead of cattle manure, especially where the former are from not wholly domestic sources. Tacon (1979) has made some observations on the passage of heavy metals through trout, discussed previously in Section 4.5.

Other costs of a highly uncertain nature for which no estimates have been made but which may nonetheless be significant include those associated with predator control, insurance and natural disasters (e.g. drought, flooding, etc).

In conclusion, therefore, it would appear that the production of worms as a feedstuff is feasible from the strictly biological view, and that it is possible to convert cheap animal manures into a much higher value of animal protein nutritionally suitable for use in trout diets. Economic viability also appears to be plausible, but the technological feasibility remains as yet open to some question.

5.4 CULTURE OF MAGGOTS

5.4.1 Larvae of the common house fly, Musca domestica, have been considered as a potential food material for a substantial period, and as long ago as 1919 Lindner was suggesting that maggots might be cultured on horse dung as a source of food materials. A number of more recent workers have considered the possibility of using maggots to biodegrade chicken manure and then of feeding the maggots back to the birds in an integrated system (Miller and Shaw, 1969; Calvert, Morgan and Eby, 1971; Calvert, Martin and Morgan, 1969).

5.4.2 Maggots have been found to contain between 46% (author's unpublished findings) and 63% (Calvert, Morgan and Eby, 1971) protein. This may be expected to vary with the method of culture, stage of growth and the diet. The material is of high quality, as may be seen by a comparison with the requirements of rainbow trout (See Appendix G). Maggots contain sufficient of all the essential amino acids in order to be nutritionally adequate for rainbow trout, with the possible exception of tryptophan where the quantities involved are so small as to be subject to significant error.

5.4.3 Maggot culture in the UK is well established and produces substantial quantities annually to supply the freshwater angling industry. The precise quantities involved are difficult to estimate on account of the large number of very small scale producers supplementing the much larger commercial ventures, but annual production is belived to be in the range of 1,500 to 5,000 tons. Angling is the only significant market for maggots, although small quantities are also used as aquarium and terrarium foods and as experimental animals in biological laboratories.

The price of maggots is currently around 70p-£1 per lb.

(Jan 1980), individual sales being generally small. The wholesale price is nearer to 50p per lb. (Savage, 1979). Much of this price may however be allocated to labour intensive operations associated with a select market - weighing, sorting, cleaning, packing, etc.

5.4.4 The high price realised by maggots for angling purposes permits the use of relatively high priced feedstuffs if these produce superior growth to low grade feeds. For this reason, high quality feeds are used instead of animal manures which, although adequate to sustain a culture, produce at a very much lower rate.

The most commonly used raw materials are meat offals, poultry by-products, industrial fish and fish offals. One large farm uses poultry mortalities from a local source and industrial fish obtained at £25 per ton (1978 prices), considerably cheaper than the cost of industrial fish for most other purposes since the quality requirements are not so rigid, and stale fish rejected from fish meal plants or held in storage for too long may be used. The materials are held in cold storage until required, whereupon they are spread out in an enclosed space with a stock of the mature flies for innoculation with the eggs, after which they are transferred to the main culture unit. This consists of a series of rectangular concrete pans, in which the maggots hatch and grow with little further attention (other than moisture and temperature control of the building) until harvesting some two weeks later, whereupon the entire contents of the pan, consisting of full-grown maggots and spent food materials, are raised on a griddle and the maggots allowed to drop back through into the pan, from which they are collected, while extraneous materials are retained. The movement of the maggots relies on a photonegative response exhibited shortly prior to pupation.

The yield may then be sorted for immediate sale or they may be chilled to slow the metabolic rate (and the onset of pupation) and so to regulate output, thus enabling the facilities to be run at near to maximum capacity for most of the year.

5.4.5 A wide variety of materials may be used to raise the larvae of M. domestica including meat offals, fish offals, industrial fish, poultry by-products, yeasts and animal manures. Conversion of meat materials averages at around 6/1, while conversion of manure appears to be very much poorer at around 30-40/1 even under good conditions (Miller and Shaw, 1969; Calvert, Morgan Eby, 1971). Growth rates on manures are also reduced.

5.4.6 Considering initially only food costs and conversion ratios, we may estimate minimum production costs using the various materials available:

Material	Price per ton (1979)	Conversion	Price per ton of Maggots: Fresh weight	Price per ton of Maggots: Dry Weight
Meat offals	£80	6/1	£480	£1,900
Stale fish	£30	6/1	£180	£ 710
Manure	£ 2.50	40/1	£100	£ 400

These figures do not compare favourably against existing compound feeds costing around £300-£400 per ton. Clearly the increased growth rates obtained using high quality feeds are insufficient to compensate for their high cost when the price of the product must compete with feedstuff materials rather than on the bait market. The poor conversion of manures also leads to a high initial cost relative to such organisms as earthworms, and when the running costs of production (labour, heating, etc) are considered, it is clear that maggot cultures are unlikely to provide an economically viable feedstuff material unless the performance of trout on such a diet exceeded expectations based on the protein content alone.

5.4.7. Very few studies have been reported on the use of maggots as a feedstuff for fish. Hickling (1974) recorded a conversion ratio of 7/1 for maggots, which is about average or slightly poorer than for most natural wet feeds. Deelder (1978), using eels and the larvae of Tenebrio molitor and the fly Calliphora erythrocephala, achieved a conversion ratio of around 3/1, but points out that eels stomachs contain more chitinase than do those of rainbow trout, and that the latter might not therefore be expected to make such good use of these highly chitinous materials. In small scale feeding trials of short duration at Stirling, frozen maggots did not appear to be particularly palatable and the trout soon lost interest and exhibited poor conversion ratios. In experience using chickens, on the other hand, Calvert, Morgan and Eby (1971) suggest that pupae of M. domestica were well accepted and when used in replacement rations, produced a performance similar to that of soya protein.

5.4.8 In view of the high feed costs incurred in raising maggots and the indifferent conversion of these items into trout flesh, there is no reason to suppose that maggots might provide an economically viable alternative to existing protein feedstuffs, even neglecting such factors as operating costs of the culture unit and the inconvenience of using this material instead of dry pellets. Furthermore, maggots offer no advantages over many other more promising candidates, such as earthworms, in nutritional value, efficiency of culture or acceptability to the fish. It is also the case that maggot units produce a considerable smell nuisance, and Seaman (1979) states that health and environmental authorities are hardening their attitudes towards this industry.

Having ruled out maggots as likely trout feed materials, the culture techniques used, and in particular the large scale of the industry and the degree of mechanisation involved, may provide useful information on the practicality of mass production of other more useful organisms.

5.5 CULTURE OF AQUATIC DETRITIVORES

Culture of aquatic detritivores has long been practised on a small scale to supplement trout diets with live food (Hickling, 1974) or for use as fry feeds (Ivleva, 1969). Their mass culture as a main feed item, however, does not appear to have been attempted other than in extensive systems, where all such natural forage is encouraged.

5.5.1 A number of organisms, many of which may be cultured together, are here considered under the general term "aquatic detritivores". These include daphnids, chironomids, tubificids, gammarids, and asellids.

5.5.2 Only Daphnia and chironomid larvae, frequently cultured together, have received detailed attention in the literature. Broadly speaking, two main methods of culture occur. The most widely used method is to manure a pond and harvest the yield of these two organisms, which may grow partly by direct consumption of the manure and/or bacteria, and partly by consumption of the primary production encouraged by the manure. Since a part of their consumption is from the primary production rather than direct consumption of the manure, conversion ratios may appear to be exceedingly good, e.g. 0.25:1 for Meshkova (Table 5.2). Against this, however, where a significant proportion of the diet is coming from natural primary production, secondary productivity is necessarily very much lower than in "intensive" systems. In intensive systems, the reverse is the case and the culture may be fed on high grade foods, such as concentrated algal cultures, with a high productivity per volume of culture but a very much poorer conversion ratio since "invisible" natural contributions to their growth are now much reduced.

While the use of high grade feeds may be permissible for cultures required to provide small quantities of fry food, this would not be practical for the large scale culture of cheap food materials and it is the first, "extensive", system that is likely to be of more interest in this context, with a possible compromise situation using activated sewage sludges where a significant proportion may be consumed directly in addition to fertilising the culture medium.

Extensive culture systems in manured ponds would not be likely to yield more than 0.1-0.2 lbs per square yard per day, even under optimum conditions, and would generally yield much less. This is partly because, with the exception of Daphnia, the organisms concerned are bottom living and hence increasing the depth of water would have very little effect on production, thus making production per unit volume a rather vague concept (unlike for example earthworms, which, within limits, may be cultured in a three dimensional medium). Having produced the organisms, there would then be very considerable difficulties in harvesting the yield, especially of the mud living chironomid larvae and Tubifex sp. The ideal solution would be to stock the pond with fish which could harvest it themselves. Trout, being highly sensitive with regard to temperature, oxygen concentration and water quality, would not be suitable for this purpose unless the level of manuring/fertilisation was so low as to seriously restrict the primary production of the pond and in consequence it would seem very much more useful to use tolerant species such as carp, as has been done in the Munich sewage lagoons for many years and more recently in Britain and the United States (Heimbuch et al, 1978; Harvey, 1979; Allen, 1969). Professor Edwards of Cardiff University believes that it may be feasible to harvest the organisms from the culture ponds (Edwards, 1979) thus making this food available to intensively reared trout, but has not so far provided an indication of how this may be done. Consequently the culture of aquatic detritivores in manured ponds is considered more likely to be of relevance to coarse fish production rather than to trout culture, and is not therefore considered in detail here.

Culture of Daphnia and chironomids on a small scale as a feed supplement for trout may still be of some value should these items be demonstrated to promote growth in trout when fed in combination with standard feeds, as has been reported to be the case with carp (Yashouv, 1956), mullet (Yashouv and Ben Shachar, 1967), and

Tilapia (McLarney, Levine and Sherman, 1978). However, it is entirely possible that compound trout pellets, being already high in animal protein, would benefit less from a live food supplement than would carp and *Tilapia* feeds.

Culture methods for *Daphnia* have been described by Heimbuch et al, 1978, and by Persoone and Sorgeloos, 1974; culture methods for chironomid larvae have been described by Yashouv, 1970, and by McLarney, Henderson and Sherman, 1974. There are also a number of papers in Russian reviewed by Ivleva, 1969. The usual culture method for both *Daphnia* and chironomid larvae is simply to manure a pond and to net the organisms for feeding as required. Yields obtained in this manner, however, are far below the optimum, mainly because of the limited space available for the bottom living chironomids. Production may be enhanced by increasing the available substrate area by hanging sheets of suitable material in the pond, as described by McLarney et al, 1974. A further advantage of this method is that the sheets may be lifted from the manured ponds and hung in the fish ponds to be grazed by the fish, thus avoiding the need for harvesting. Recommended water flows in the culture vessel vary, and probably depend on the temperature and the level of manuring.

5.5.3 *Daphnia*, chironomid larvae, *Gammarus*, *Tubifex*, *Hyallella* and *Diaptomus* were evaluated as potential feedstuff ingredients on the basis of protein content and amino acid profiles as described in Chapter 2. Their values estimated on this basis are recorded on Appendix H and range from £136 for *Hyallella* to £247 for *Diaptomus* per ton dry weight.

Should any of these items prove to promote growth when fed as a supplement, their value would be much enhanced but since no direct evidence exists for such an effect on trout it would be fruitless to conjecture on their likely value in this respect.

5.5.4 None of the various techniques and systems of producing aquatic detritivores were costed since it was decided that they would all lie far outside the range of economic viability for us as a main feed item. It is not considered likely that aquatic detritivores can provide an economic feedstuff for use in intensive trout feeds, in view of protein qualities, productivities and/or conversion ratios, and unknown variables connected with harvesting the yield.

Should any of these items prove to promote growth when fed as a supplement, however, then a revision would be necessary, although it is likely that even in these circumstances they would need to be beneficial in very small quantities for their production to be worthwhile. One interesting suggestion that should be mentioned before leaving the subject of aquatic detritivores is that should chironomid larvae be demonstrated to contribute U.G.F. to a diet, then they could conceivably be cultured on substrate materials hung in the trout farms own effluent, utilising the waste products and bacteria therein, to be transferred to the fish ponds at suitable intervals.

5.6 USE OF MACRO-ALGAE IN CULTURE OF AQUATIC DETRITIVORES

5.6.1 The term macro-algae is used here to include all the larger species of algae commonly known as seaweeds. These are used as food in Britain only to a very limited extent, although *Porphyra*

("Laver bread") and Rhodymenia ("Dulse") are occasionally used in this fashion. Seaweeds are used on a small scale in the North and West of Scotland as fertilisers, and are also grazed by sheep and deer on some of the more remote islands where winter fodder is scarce. The major agricultural use of seaweeds, however, is as the derived product alginate incorporated in compound feeds in small quantities to act as a vitamin binder additive. In addition to alginate, seaweeds provide the raw materials used in the extraction of agars and iodine, although in Britain these latter industries are small.

5.6.2 Seaweeds used for human consumption - Porphyra and Rhodymenia - are highly priced and are not therefore considered for use in aquacultural feedstuffs, both being themselves the object of aquaculture in some countries. The seaweeds considered for use here are predominantly Ascophyllum and Laminaria, these being abundant on rocky coasts around Scotland. Ascophyllum and the stipes of Laminaria are collected for use in the alginate extraction industry, and fetched around £7.50 per ton and £50 per ton (wet weight) respectively in 1979 (MacPherson, 1979). These prices appear to have remained stable to the present.

Ascophyllum is cut at low tide and collected in floating nets placed to catch drifting materials as the tide comes in. Laminaria stipes are collected from driftweed on the strand line. Attempts by Scottish Alginate Industries Ltd. to develop mechanical weed cutting devices have not so far met with sufficient success to replace the traditional methods described.

The quantities of seaweeds used in alginate extraction are very much less than the potential supply (Blackwell, 1979) while quantities used by crofting communities as green manure are not known.

A survey of selected sites on Uist and Barra indicated an average standing crop of 130 tons per mile of coast line surveyed, some 60% of this being Ascophyllum (Manpower Services Commission, 1977). It has been further estimated that there are at least 250,000 tons of fucoids in the intertidal zone around Scotland and more than 110,000,000 tons of Laminaria sp. in the shallow subtidal zone to twenty metres depth (Powell, 1979). Prentice (unpublished) suggests the rather lower figures of 180,000 tons and 10,000,000 tons respectively, but does not specify the depth to which his subtidal zone extended. The relationship between biomass and production in this area is not known, but a study on the East coast of Canada (Mann, 1972) suggested the sub-littoral annual productivity for 3 seaweeds (two species of Laminaria and one species of Agarum) as being between 1 and 20 times the standing biomass, although much of this production replaced material lost through fraying at the ends.

In addition to seaweeds collected specificially for the purpose, there are three other possible sources of material for organic cultures - drift weed, alginate industrial residues and cultured seaweeds. Of these, cultured seaweeds may be quickly eliminated as being too highly priced.

Drift weed accumulates seasonally at various localities along the British coastline, depending on prevailing currents and climatic condition. Such drift weed is largely useless for industrial purposes, unless sorted by hand as for Laminaria stipes, since the processes used are generally designed for a single material free from contamination with other species and extraneous matter. Material such as this therefore has no current economic value although it is frequently collected from beach resorts and dumped by local council authorities.

The quantities involved are not known but are almost certainly not large - as one example, Scarborough Borough Council reckons to dispose of 200-250 tons annually (Waterson, 1979). Where available, however, these materials would often be free except for the cost of transport, and might therefore be used to supplement more regular supplies of bought materials. The species composition of this drift naturally varies with the season.

Seaweed residues from the alginate extraction industry retain most of the nutritive value of the original material, but may be adversely affected by the alkali extraction chemical processes used. Residues are currently produced in the form of a slurry containing 2%-5% solids. Scottish Alginate Industries have shown interest in drying this and marketing it as a feedstuff additive, and small samples have been produced, but the cost of drying would exclude it from use as a substrate for the production of intermediate food items. The slurry itself could, however, conceivably be used if piped directly from the production site.

5.6.3 Little work has been done on the nutritional value of seaweeds, such analyses as have been conducted concentrating on the content of useful salts such as Iodine. The very small number of nutritional analyses available show a relatively low protein content:

	% Dry Matter	% Protein	% Carbohydrate, Fat and Ash	Source
Seaweed Meal (Laminaria and Fucus)	89.4	10.7	78.7	N.A.S.
Alginate Residues (dried)	90.0	14.4	49.5	S.A.I.

The low nutritional value and the low digestibility of seaweeds to many vertebrates combine to reduce the value of seaweeds as a direct stock feed and make upgrading via invertebrate intermediaries desirable. Alkaline extracted residues may retain some residual chemicals and have been shown to contain some 6 ppm Copper, 7 ppm Lead and less than 1 ppm Arsenic. It is not however anticipated that these levels would adversely affect nutritional quality.

5.6.4 The main herbivores feeding on brown seaweeds around Britain are gastropod snails (Littorina littoralis and Gibbula species) and several small crustaceans, particularly amphipods. Some work has been done in Japan on the culture of the copepod Tigriopus japonicus on beds of crushed seaweed as a live food for fish fry (Provasoli et al, 1959; Ito, 1970; Rothbard, 1976), but these copepods appear to prefer green seaweeds and are probably not major consumers of brown seaweeds in the UK. Furthermore, it is doubtful whether these organisms would be large enough to interest trout unless concentrated and incorporated in pellets for use.

The two gastropod types mentioned feed on living brown seaweeds and are considered unlikely to be capable of satisfactory culture on cut material, and would also require extraction from their shells for use as a feedstuff. Species of marine amphipod appear to offer the best prospects for culture. Talitrus saltator is one of the commonest species and could potentially lend itself particularly well to intensive culture, exhibiting the following useful attributes:

- It has become virtually a terrestial animal, living among sand and weed detritus around the high tide mark. T. saltator does not appear to require a high moisture content in the sand, or daily tidal submersion; it does, however, appear to require the presence of salt in its habitat (Yonge, 1973). It could therefore probably be cultured in inland as well as onshore sites.

- It reproduces by means of eggs carried in a brood pouch, the adult female remaining in a burrow while the eggs develop. Planktonic marine larval stages, prevalent among some crustacean groups, are thus dispensed with.
- It is a moderately prolific breeder and has a relatively short life cycle of around one year.
- It is highly tolerant of crowding and may occur in nature at extremely high densities.
- They are potentially easy to harvest, being attracted by lights at nightwhich may be placed over collecting containers for removal.
- They may be kept alive for substantial periods, if kept cool and moist, prior to feeding.
- They remain alive in fresh water for substantial periods, and will not in most circumstances remain uneaten so as to pollute the fish ponds.
- They are indiscriminate feeders, and will eat a great variety of organic wastes, both animal and vegetable, in addition to rotting seaweeds, thus permitting exploitation of other locally available waste materials (Moore, 1979).

There does not appear to have been any substantial experimental work on the culture of amphipods, and while they may easily be demonstrated to survive for long periods in containers of seaweed and damp sand, productivity and conversion ratios have not been recorded. A certain amount of practical work is therefore required before the culture of these organisms may be properly evaluated. It is suggested that it would be possible to culture amphipods in net enclosures to retain heaped seaweeds sited on the shore at the high tide line and near to the source of the raw materials in order to keep down transport costs. The mesh size would be such as to retain the seaweed but to allow free access and egress to the amphipods, which it is assumed would largely remain within the weed mass, being a favourable environment. Harvesting could be conducted on a regular basis, using lights to attract the organisms to collecting containers of sufficient depth to prevent subsequent escape, or, on a more intermittent basis, a grille which would retain the weed but allow the amphipods to fall through.

The system envisaged is admittedly highly speculative at present, but Comhairle nan Eilean has shown some interest and it is hoped that the required experimental work may be taken up by some such body with the necessary practical facilities (especially regarding a suitable site) in the near future.

A number of other amphipod species besides T. saltator inhabit similar environments and would probably be present in any culture unit designed for the latter. These would, however, probably prove similar in nutritional value and may be safely ignored.

5.6.5 T. saltator was analysed and found to contain approximately 40% protein by dry weight. No amino acid analyses are available but it is expected that this would resemble the similar freshwater Gammarus (Appendix D) which contains all the essential amino acids to excess of the trout's requirements, with the exception of a slight deficiency in the Methionine-Cystine combination. Limited feeding trials using T. saltator fed to fingerling rainbow trout for a period of less than a month suggested that conversion ratios would bein the region of 6/1, similar to the conversion ratio of 3.6-6.6/1 recorded by Hickling for Gammarus (Hickling, 1974) Live and frozen amphipods are both avidly consumed by trout.

5.6.6 As a live feedstuff for farmed salmonids, marine amphipods have a number of desirable qualities. They have proved highly acceptable to trout, and appear to be of good nutritional quality. In addition they are relatively simple to keep alive on the farm site until fed, whereupon they will remain alive in the fresh water for considerable periods, and, being discrete units, should result in little wastage. They could perhaps be even more useful in marine salmonid culture systems, and could be produced in an integrated unit to reduce handling and transport charges.

Seaweeds, the raw materials used, are available in very large quantities at a relatively low price of around £7.50 per ton, which could make amphipods competitive with commercial feeds provided conversion ratios for seaweed/amphipods of 10/1 or less could be achieved. It is possible that other cheaper sources of seaweed might be exploited, and Scottish Alginate Industries Ltd. is continuously studying improved methods of harvesting and collecting seaweeds.

A full amino acid analysis of T. saltator and extensive feeding trials using this organism in rainbow trout diets would be useful in confirming the nutritional value of this item.

Comhairle nan Eilean and the Highlands and Islands development Board have shown frequent interest in possible alternative uses of seaweeds in their respective areas, and possible financial assistance could potentially be forthcoming from the latter for any such enterprise.

5.7 TERMITE CULTURE AND USE OF WOOD SUBSTRATES

5.7.1 The culture of termites on the residues of Scottish softwood production was considered. Scottish softwood production is currently in the region of 700,000 cubic metres per annum, of which approximately 210,000 tons is classed as "residual material", 67% being used by secondary wood processing industries and 33% remaining unused. (ScottishForestry Commission, 1979). Residual materials used by the processing industries may be obtained at a price of around £7-£8 per ton, while the cost of those residues remaining unused is uncertain. In the past the Forestry Commission has been prepared to contract out areas of felled woodland to outside interests such as firewood merchants. In general, however, these residues remain unused because the cost of retrieval exceeds the estimated value of the material.

Wood residues could conceivably be used in two general ways:

1) As a direct feed supplement to livestock, especially ruminants, with or without prior chemical or physical treatment.
2) As a substrate for the culture of high-protein wood-eating organisms as an animal feedstuff.

The technological and biological feasibility of utilising wood residues in this fashion has received little attention to date, probably as a result of the poor nutritional quality of wood residues.

5.7.2 With the exception of bark (which contains a high percentage of living cell matter), the wood residues under discussion are chemically and nutritionally similar to the prime product. Woody tissues are typically high in carbohydrates and low in proteins. The low protein levels are enough in themselves to make such materials of limited value as a feedstuff unless combined with some cheap non-protein nitrogen source such as ammonia or urea. Furthermore the nutrients that are present are not readily accessible. Pinus silvestris has been shown to consist very largely of cellulose (41%) and lignin (29%) (Seifert and Becker, undated), both materials being resistant to breakdown and highly indigestible to many animal species. The use of these nutrients would therefore require either physico-chemical treatments prior to feeding or alternatively the culture of a species of organism capable of breaking down these woody components.

5.7.3 Wood residues have been proposed as a direct feed source for certain stock, in particular ruminants, but this is considered highly unlikely. While cattle are capable of breaking down cellulose (by virtue of bacteria contained in the rumen), the high lignin content of wood makes this material relatively indigestible. Direct use of wood residues as an animal feedstuff is not therefore thought likely to become a factor in competition with indirect usage of this resource.

5.7.4 The high lignin and cellulose content results in few macro-organisms being able to utilise wood directly as a source of food, although a number (millipedes, earthworms, woodlice, etc) are able to digest partially decayed wood and/or the organisms (fungi, bacteria) breaking it down.

Macro-organisms that can utilise wood directly as a source of nutrition include many termite species, wood-boring beetles and two genera of cockroaches, Panesthis and Cryptocercus. Of these the termites were considered to be the most potentially useful for further study, both wood-boring beetles and the cockroaches being ill-adapted to an exclusively wood diet and reflecting this in reduced fecundity, growth rate and growth efficiency. Furthermore, in the case of wood-boring beetles, the diet of wood generally only applies to one or more of the immature stages, and they are unable to complete their life history in this medium.

Following suggestions from the Termite Research Unit of the Centre for Overseas Pest Research, two species of termite, Reticulitermes santonensis and Zootermopsia nevadensis, were selected as being most suitable for the purposes of further study. Both species are easily cultured, relatively fast growing and temperature tolerant. In addition both species are capable of living in "unstructured" wood - sawdust, chips, etc - as opposed to wood-boring beetles and certain other termite species which require solid blocks in order to survive satisfactorily. A literature search failed to reveal any information on conversion efficiencies achieved by termite species, although literature on assimilation efficiencies was encouraging (Seifert and Becker), suggesting that various termite species assimilate between 74% and 99% of cellulose and 2% - 83% of lignin. However, most of the assimilated food is believed to be expended as energy (Williams, 1979).

Feeding trials were therefore set up using R. santonensis and Z. nevadensis colonies obtained from the Termite Research Unit, but were abandoned after two years when it was found that the colonies of neither species had made appreciable growth and conversion ratios were extremely poor, probably in the region of 50:1 although the very small growth increment of the colonies would make such measurements liable to significant errors.

The slow growth rate may also be a result of the poor nutritional quality of wood, and in particular of the low nitrogen content, although termites have not been found to respond well to artificially added nitrogen, indicating the possibility of other causes (Williams, 1979). The apparently poor conversion combined with the high price of wood residues relative to other organic wastes (especially manures) would make the prospect of culturing termites as a proteinaceous feedstuff highly remote from an economic standpoint.

Apart from the poor productivity, a number of other factors mitigate against the use of termites in this manner. The termites which are easily cultured all form diffuse nests, and could not therefore be easily extracted from the faeces and residual materials still present when the colony achieved maximum size. Were it intended to harvest the whole colony at one time, then it is probable that the termites could be sieved out without much difficulty. On the other hand, productivity might well be greater if a continuous culture system were employed, creaming off a known (small) proportion of the colony daily at a level which could be readily replaced by colonial growth in an effort to attain the maximum sustainable yield.

In addition to the unknown harvesting costs, further intangibles result from the security aspect of culturing termites. The Ministry of Agriculture, Fisheries and Food stipulates that termites, as potentially harmful pests, should be kept only under strictly controlled conditions. In practice, this has meant "escape-proof" laboratory conditions, e.g. in screw-top jars, sealed tanks, etc. It is likely that, were termites to be raised on a substantial scale, equally stringent precautions would need to be enforced, and these might be expected to add considerably to the costs of such a venture.

5.7.5. Termite sp., considered as a group by the F.A.O., have been analysed as follows:

Protein	20.4%
Fat	28.0%
Carbohydrate	4.2%
Fibre	2.7%
Ash	2.9%
Moisture	44.5%

On the basis of the protein content, a conversion ratio in the region of 6/1 for termites/trout might reasonably be expected, resulting in a feed value of not more than £100 per ton. This feed value is of course only approximate. Termites were acceptable to trout in the extremely small quantities available.

5.7.6. The value of termites as a feedstuff was not thoroughly investigated, but could be suggested from a full amino acid analysis or from extensive feeding trials. In the event, however, it was considered that the low productivity and high probable costs of termite culture made their use in trout diets extremely unlikely, and further effort in this direction was not therefore considered to be justified.

CHAPTER 6

Manner of use of materials

6.1 MANNER OF USE OF MATERIALS

In the course of this thesis a number of proteinaceous materials have been considered as potential trout feedstuffs. While the suitability of these materials as regards acceptability and nutritional value has been considered, the manner in which they may be fed to the trout has received little attention.

Certain animal-derived materials believed to be nutritionally complete in terms of the trout's requirements, either on the basis of their chemical analyses as summarised in Appendices D and G or on the basis of historical experience, could be fed in isolation with little or no prior preparation as an exclusive diet. Thus for instance fresh sea fish could be distributed whole to trout of sufficient size, many of the cultured organisms (maggots, earthworms) could be fed live, etc. The majority of the materials that have been considered, however, lack one or more ingredients essential to the full development of the fish or alternatively occur in a form which could not conveniently be distributed in water without some form of prior processing. Furthermore, in virtually all cases, greater biological efficiency may be achieved by using a mixture of materials such that high protein ingredients are "diluted" with lower quality ingredients in a proportion that maintains the nutritional value of the whole diet at a level sufficient to satisfy the trout's requirements and yet at the same time reduces the levels of those components surplus to the fish's requirements which would otherwise be partially wasted. Linear programming least cost techniques are utilised to determine the optimum mix, and the greater the initial range of raw materials available for inclusion, then the better are the prospects for reducing wastage of materials to a minimum.

It is naturally possible to feed several complimentary items together but without prior mixing. However, the danger with this approach is that individual fish may select one or other of the materials to the exclusion of all else (as is indeed shown to be the nature of wild brown trout - see Section 1.2.1) with the result that certain fish will be deficient in one nutrient while others are deficient in another.

An alternative method might be to feed the fish several unmixed items separately on a rotational basis, in an attempt to prevent the fish from selecting for any one particular item. Unfortunately this is likely to result in all the fish being deficient in certain nutrients which are not stored by the fish in any appreciable quantities or for substantial periods of time, e.g. vitamins, carbohydrates, etc.

A second alternative is to mix all the ingredients into a homogeneous paste/meal and to produce pellets. A dry compound pellet, as produced by the proprietary commercial fishfood manufacturers, is satisfactory as regards feeding the trout but is expensive to produce, incurring high costs in reducing all the materials to a dry meal form and in producing the hard pellet. Such meal reduction and pelleting plants are capital intensive (See Section 3.1). These considerations negate the very advantages we are seeking in propounding alternative feedstuffs, and the production of dry compound pellets is not likely to be economically feasible on the individual scale of most trout farms. Production of moist pellets by contrast is both simple and relatively cheap, achieved by mixing a number of dry meals with a proportion of fresh wet ingredients. It is to this aspect of trout feeding that the rest of this chapter is largely devoted.

6.2 MOIST PELLETS IN AQUACULTURE

6.2.1 Intermediate moisture foods developed as a logical extension of the traditional wet diets used in fish culture, a number of these wet feeds frequently being mixed together to improve their combined nutritional value, to increase the binding properties of the feed in water or to stretch out a feedstuff in short supply. As fish farms expanded in size and the supplies of locally available fresh material became inadequate, so it became necessary to rely increasingly on stored meals for mixing in with the wet ingredients, producing an intermediate moisture product which could be either pelleted or fed as a paste. Originally such diets were formulated largely on the basis of guesswork or practical experience, but in recent years our rapidly expanding knowledge of the trout's dietary requirements has permitted increasingly sophisticated formulations and led to the development of commercial and semi-commercial moist pellets in the USA, beginning with the Cortland pellet of mixed meat and meal in the 1940's and continuing with the more recent and widely used Oregon moist pellet and Abernathy style moist diets, being made up either of a mixture of dry and fresh wet materials or alternatively of dry meals with water added just prior to pelleting (See Table 6.1 for formulations of some typical moist diets). A large number of variations on this theme have been produced by farmers for their own use, while in Britain the White Fish Authority prepare their own moist pellets for the pilot scale culture of sole and turbot, having found moist pellets better accepted by the fish than were the hard trout pellets originally used.

6.2.2 The advantages and disadvantages of moist pellets over wet feeds and dry compound pellets are briefly summarised in the following sections.

6.2.2.1 Moist pellets exhibit a number of significant advantages over fresh wet foods, the most important of which are as follows:

1) Pellets may be of a fairly uniform size, which can be tailored to that most readily acceptable to fish of particular sizes. This compares favourably with most minced wet foods which contain a wide range of particle sizes.
2) Related to (1) (above) the uniformity of size reduces the possibility of fish choking on food particles too big for them to swallow.
3) Binding materials are usually incorporated in moist pellets, reducing the breakup of the pellets and the loss of nutrients to the water. Most wet feeds lose a significant proportion of their nutritive value through leaching of soluble nutrients and the breakup of the material into particles too small for the fish to consume. Binders added to minced wet feeds may help to considerably lessen this problem, but not generally to the same extent as when used in conjunction with moist pellets.
4) Related to (3) (above) is that the reduced loss of nutrients to the water also reduces the pollution load in the culture unit, thus alleviating problems of oxygen tension and disease

through poor hygiene. In some countries, e.g. Denmark, strict laws governing effluent quality may virtually exclude the continuing use of simple minced wet foods without substantial treatment of the effluent or the availability of large quantities of fresh water to permit adequate dilution.

5) By incorporating all the dietary ingredients in the one pellet, the fish are assured of a nutritionally adequate diet and will not select particular items only.

6) The raw materials may be mixed to provide a nutritionally adequate diet at a relatively low price, incorporating cheap ingredients such as cereal grains. Fresh materials that are nutritionally adequate in their own right on the other hand are almost entirely restricted to the high-cost animal based protein materials.

7) Related to (6) (above), the composition of the diet may be adjusted at will to suit the individual requirements of the farmer, e.g. protein levels may be increased for broodstock and fry, or reduced during cold weather or for holding stock etc, by altering the proportion of high protein materials to cheaper vegetable fillers. The composition of fresh foods, however, is dependent rather on factors external to the farmer's control - season, climate, etc.

8) The relatively low moisture content of intermediate moisture pellets slows microbial decomposition of the feed such that the pellets may be stored unfrozen for short periods of time. Fresh wet foods invariably require refrigeration if they are to be kept in good condition for more than a day or two.

9) Various ingredients may be incorporated in the pellet as required,

such as vitamins, medicinal compounds, pigments, etc. While these may also be added to minced wet diets, they tend not to be quite so thoroughly bound to the feed in these circumstances and are more liable to wastage and leaching with the consequences that dosages may not be so strictly controlled.

10) There are a number of automatic feeder designs suitable for use with moist pellets. The range of automatic feeders suitable for feeding minced wet diets is rather more restricted. (See Figs. 1.2-1.8).

11) Depending upon availability and price, dietary ingredients may exhibit mutual substitutability without affecting the overall characteristics of the diet or the appetite of the trout. Substitution of one wet food by another, however, e.g. fresh fish by meat offals, may result in a temporary lowering of the trout's appetite until they become used to the new diet (See Chapter 1).

12) Related to (11) (above), provided that a wide range of ingredients are available, stability of price and supply is obtained since shortages of one material are usually easily compensated by similar ingredients. (See Appendix G).

13) The reduced water content of intermediate moisture pellets makes them easier to handle and less expensive to transport than wet foods should this be required.

14) Intermediate moisture pellets closely resemble commercial dry compound pellets, should it prove expedient to switch from one to the other at short notice, facilitating adaptation on the part of the trout.

6.2.2.2 The major disadvantages of moist pellets over fresh wet foods may be summarised as follows:

1) More processing is required, with associated costs of labour.
2) If moist pellets are to be kept for longer than three or four days (see Section 6 on spoilage), freezing may be required. The whole pellet would then need to be frozen, rather than just the wet component of a wet food/meal mixture.
3) The wider range of ingredients necessitates more elaborate quality control to prevent the introduction of disease to the fish ponds. On the other hand processing (especially when cooking is involved) and the reduced water content combine to counteract the development of many disease organisms, so that the net advantage in this instance is uncertain.

6.2.2.3 On balance, a correctly formulated moist pelleted diet would seem to be far preferable to a wet diet except in those circumstances where a high protein animal material is available in the fresh state on a regular basis and in substantial quantities, and at a cost low enough such that a mixture with other ingredients, e.g. vegetable materials, does not result in significant cost savings. Such circumstances, although undoubtedly rare, may arise near fishing ports where industrial fish species are regularly landed.

The relative advantages of moist pellets and of dry pellets are rather more ambivalent and should be seen in the context of individual circumstances. In many cases the advantages of dry pellets over moist pellets are the same as the advantages of moist pellets over fresh wet foods, only carried one stage further.

6.2.2.4 The major advantages of moist pellets over dry pellets are listed below:

1) Moist pellets are said to be more acceptable to a number of fish types, including salmonids. While oft repeated for salmonids in general (e.g. Ghittino, 1979; Hastings, 1979; Bardach et al, 1976; Webber and Huguenin, 1979) such a preference in rainbow trout, although quite plausible, has yet to be satisfactorily demonstrated.

2) Moist pellets may give better conversion ratios on a dry weight of food/live weight of fish basis than do dry pelleted feeds. There are a number of possible explanations for this, the most widely accepted of which is that the provision of fresh water in the feed is beneficial from the aspect of osmotic balance of the fish. In salt water of course this is of greater importance on account of the extra energy required in extracting and eliminating the salt from sea water. Many European salt water farmers are reported to moisten dry pellets with fresh water prior to feeding (Ghittino, 1979). An alternative explanation for the better conversion figures is simply that increased palatability (See (1) (above)) leads to an increased consumption and hence an increase in the ratio of consumption/maintenance requirement, and hence an increase in the proportion of the diet contributing to growth. It may be a combination of these and other factors and it is suggested that further experimental study is required before any firm conclusions can be drawn.

3) Moist pellets are very much simpler and cheaper to produce than

are dry pellets and may be prepared with relatively little capital equipment on a small scale suited to a farm's individual requirements.

4) If produced on site, moist pellets may be formulated by the farmer according to his requirements, and may also be used to incorporate locally available or temporarily cheap ingredients (including cultured foods) not available in sufficient quantity or at low enough price to justify their transport and reduction to dry meal. This is of particular interest in the current context of the utilisation of such materials. It would also be possible to produce moist pellets from mixtures of meal and fish silage and/or blood, provided that the latter did not constitute more than about 8% of the diet by dry weight (approximately 40% by wet weight) as this would produce a paste rather too wet for adequate pelleting. These materials could not be incorporated in dry pellets without greatly reducing the water content and increasing the cost to such an extent as to destroy much or all of the economic attraction of these materials.

5) Related to (4) (above), moist pellets prepared on site may be varied according to changing requirements, whereas commercially prepared dry pellets are available in certain standard categories of size and nutritional content only. It has been suggested on a number of occasions (Hastings, 1973; Huguenin and Webber, 1979) that it is economically more efficient to raise protein levels in the diet when the fish are feeding actively and to lower the protein content when the growth rate is slowed by low water temperatures.

6.2.2.5 The disadvantages of moist pellets compared with dry pellets are fairly numerous, and have so far prevented the use of moist pellets in UK aquaculture on a substantial scale. The major disadvantages are:

1) Moist pellets cannot be generally stored for more than a few days without prior refrigeration. (The keeping properties of moist pellets may be improved by maintaining a low water content or by the addition of certain microbicides - see Section 6.2.6 on spoilage.
2) Moist pellets take up more space than an equivalent quantity of dry pellets due to the extra water content. They also weigh more, and thus incur increased costs of handling and also transport where this is necessary.
3) Moist pellets are not so well suited to methods of automatic feeding as are dry pellets, although certain designs of feeder may be used (see Figs. 1.2-1.8).
4) Water stability is not generally as good as that of dry pellets (although contrary reports exist) even when binding materials are added, such that breakup and wastage of the pellets are greater, with a concomitant increase in the pollution load of the ponds and of the effluent.
5) Commercial moist pellets are not readily available in the UK and must usually be prepared by the farmer himself, complicating the running of the farm and increasing labour costs. This is probably the single most important factor mitigating against the use of moist pellets.
6) The quality of moist pellets is more likely to vary than that of commercially prepared dry pellets which undergo rigorous quality control checks.

7) There is a greater risk of the introduction of disease organisms via moist pellets.

8) Security of supply is reduced using moist pellets unless sufficient alternative sources of raw material are available and/or the farm has sufficient on-site storage facilities to stockpile against seasonal/unforeseen shortages.

6.2.2.6 Having listed the various advantages and disadvantages of wet foods, moist pellets and dry pellets, it can readily be seen that a number of the factors mentioned - security of supply, availability of raw materials, etc - will vary widely from one site to another and must therefore be considered on an individual farm basis, whereas other factors, such as cost of dry meals, labour, etc, will be largely common to all, excepting minor regional variations. While virtually all farms will have ready access to prepared meals, the availability of wet materials varies more widely and some farms may have regular access to cheap materials but in small quantities only, whereas others might have access to large quantities of cheap material but only on an intermittent basis, as with periodic gluts in some fish landings. Considering the very wide range of possible moist feed formulations, a number of examples are costed to provide an indication of the economic effectiveness of moist pellet feeding.

6.2.3 The range of dietary formulations satisfying the rainbow trout's nutritional requirements as summarised in Section 2.6 is virtually inexhaustible, but in practice most formulations tend to make use of a relatively small number of ingredients - often no more than 5-10 major ingredients plus ready-mixed vitamin/binder additives.

TABLE 6.1. Formulation and Composition of Some Typical Moist Diets.

INGREDIENTS.	PERCENT INCLUSION BY WEIGHT (AS BOUGHT)													
Diet No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fresh Industrial Fish.					49.0	10.0	20.0	45.0	30.0					
Herring Meal.	27.0	34.0	23.0											
White Fish Meal.				33.37	21.5	15.0	40.0			25.0		12.0	12.0	11.0
Tuna Viscera.	20.0	15.0												
Turbot.	10.0	15.0												
Queen Offal.						42.0	20.0							
Shucked Mussel						10.0								
Crab Meal.		2.0												
Nephrops Waste.									20.0					
Beef Liver.										12.5	12.5	25.0	25.0	15.0
" Spleen.										12.5	12.5	25.0	25.0	35.0
" Blood.														
Blood Meal.			17.5			5.0					25.0			
Meat Meal.														
Dried Skim Milk.	4.0		10.0							25.0	25.0	12.0		
Dried Whey.				12.75										
Soybean 49%.					21.0									
Wheat Germ Meal.	5.0	5.25	17.0	12.38										
Cottonseed Meal.		15.0	14.2	11.25						25.0	25.0	12.0	12.0	11.0
Wheat Middlings.	11.3		15.5									12.0	12.0	11.0
Oak Groats.		5.0												
Distiller's Solubles.	5.0												12.0	11.0
Dried Brewer's Yeast.	3.0													2.0
Soy Lecithin.					1.0									
Herring Oil.		6.3			5.0									
Cod Liver Oil.	1.0													2.0
Soybean Oil.			5.1	4.5										
Alginate.					1.0									
Salt + Minerals.												2.0	2.0	2.0
Vitamin Additives.	1.0	2.45		0.75										
Vitamin/Binder Mix.			4.0		1.5	18.0	20.0	5.0	3.0					
Commercial (low animal protein) prepared meal.								50.0	47.0					
Other.	2.7													
Added Water.				25.0										
Composition. % by weight				369	522				459					
Water.	36	33	8	32	48	49	38	42	40	33	33	40	40	40
Protein.	31	35	46.5	30	26	20	28	33	33	39	44	28	27	26
Fats and Oils.	7	11.5	10	7	9	2.5	2.5	8	8	3.5	2.5	3.0	3.0	3.0
Carbohydrate.								11	11					
Ingredients Cost per ton. (£s per ton dry weight).	— See Table 6.3.													
Source.	Hastings, 1969.	Crawford et al. Oregon Moist Pellet. (Dry Base).	Fowler & Banks, 1976.	Abernathy Moist Pellet.	Solberg, S.C., 1979.	W.F.A. (Pers. Comm.)				Halver, 1972.				

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" Spleen.										12.5	12.5	25.0	25.0	35.0
" Blood.														
Blood Meal.			17.5			5.0					25.0			
Meat Meal.														
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Cod Liver Oil.	1.0													2.0
Soybean Oil.			5.1	4.5										
Alginate.					1.0									
Salt + Minerals.												2.0	2.0	2.0
Vitamin Additives.	1.0	2.45		0.75										
Vitamin/Binder Mix.			4.0		1.5	18.0	20.0	5.0	3.0					
Commercial (low animal protein) prepared meal.								50.0	47.0					
Other.	2.7													
Added Water.				25.0										
Composition. % by weight				369	522				459					
Water.	36	33	8	32	48	49	38	42	40	33	33	40	40	40
Protein.	31	35	46.5	30	26	20	28	33	33	39	44	28	27	26
Fats and Oils.	7	11.5	10	7	9	2.5	2.5	8	8	3.5	2.5	3.0	3.0	3.0
Carbohydrate.								11	11					
Ingredients Cost per ton. (£s per ton dry weight).	— See Table 6.3. —													
Source.	Hastings, 1969.	Crawford et al. Oregon Moist Pellet. (Dry Base).	Fowler & Banks, 1976.	Abernathy Moist Pellet.	Solberg, S.O., 1979.	W.F.A. (Pers. Comm.)				Halver, 1972.				

This gives the producer sufficient scope to vary the proportions of ingredients to arrive at an optimum formulation consistent with the circumstances (price, availability, etc) and yet at the same time keeps the logistics and the preparation of the diet fairly simple. The range of moist diets that have at one time or another proven suitable for fish culture is extensive, and a representative selection of those that have been reported in the literature is summarised in Table 6.1. It must be appreciated that the raw materials themselves vary to some extent in both quality and price, depending upon the source and manner of processing of the material, particularly with regard to abattoir meal products and also to some extent with fish meal. Many of the vegetable materials on the other hand are of fairly uniform quality and price.

From the ingredients costings given in Table 6.3 it can be seen that many of these formulations compare favourably with commercial "dry" pelleted feeds when allowance is made for the fact that these latter usually contain some 7-10% water themselves. Most of the diets listed could be modified to become more economically attractive by the application of linear programming least cost techniques subject to the nutritional requirements of the trout.

While ingredient costs may in some cases be considerably lower than are standard commercial pellets, allowance must also be made for the cost of preparation which negates the benefits of many such moist diets unless advantage is taken of low-priced materials as they become locally or seasonally available.

6.3 PREPARATION OF MOIST PELLETS

6.3.1 The three main steps in the preparation of moist pellets are grinding, mixing and pelleting. Grinding may be dispensed with in some cases, e.g. where an Abernathy type diet is prepared from dry meal ingredients with added water only. Where wet materials require to be stored for considerable periods prior to use, or where the moist pellets themselves must be stored for long periods, then cold storage facilities and possibly also freezing facilities will be required.

All wet and/or solid materials require to be thoroughly minced or ground prior to mixing to ensure homogeneity in the finished pellet. Where frozen materials are used an initial stage using a frozen block grinder is required to reduce the particle size to a level that can be managed by the mincer. The output from the mincer should be via a die plate of appropriate hole diameter.

After mincing, the wet materials are thoroughly mixed mechanically along with the dry materials and any additives such as vitamin premixes, binders and mineral compounds. Dough mixers are reported to be fairly good when output is on a moderately small scale, while there are also a number of agricultural feedstuff mixers produced specifically for this purpose.

The moist mix is extruded via a pelleting machine or a spaghetti machine, the extruded strings being cut to the required length by a rotating cutter over the die plate. The pellets may then be used immediately or over the next two or three days (or possibly longer if antibiotics have been added or the final moisture content is low). If the food is prepared in batches for use over longer periods, however, freezing and cold storage will be required to slow deterioration of the product through the action of moulds.

6.3.2 The cost of preparation of moist pellets will vary considerably depending on the system of production (batch or semi-continuous), the scale of the operation and the nature of the ingredients. Accordingly a number of representative examples are costed in Appendix M on the basis of machine capacity and labour requirements at January, 1981 prices, all being based on the production of 600 tons of moist pellets p.a. intended to feed a unit producing in the region of 150-200 tons of trout p.a. depending upon the quality and water content of the material. A summary only of these costed examples is presented here in the form of a matrix relating cost of preparation to the form of the ingredients and to the size and regularity of each production batch (Table 6.2)

From the examples costed, a clear pattern emerges that economies may be achieved in increasing the batch size up until that point where the batch is such that it cannot all be used within a short time governed by the spoilage period, usually 3-4 days. This is one situation where a co-operative of neighbouring fish farms might be of considerable benefit, permitting batch sizes to be greatly increased. After this limit is reached an increasing proportion must be frozen prior to use, adding greatly to the overall cost. Note however that should a farm already possess freezing and/or cold store facilities for other purposes, e.g. to store the wet ingredients, then spare capacity may be used, i.e. as the ingredients are taken out of the store, so may the finished product be returned (and vice-versa as the pellets are used). In these circumstances, the costed examples will overstate the true cost of freezing and cold storage of the moist pellets. It should further be noted that a depreciation period of deterioration of the product through the action of moulds.

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TABLE 6.2 COST PER TON FOR SYSTEMS PRODUCING 600 TONS OF MOIST PELLETS PER ANNUM (JAN 1981 PRICES)

Batch Size and Run Frequency (as described in costed examples in Appendix M)	Using Fresh Materials	Using Frozen Materials	Using Dry Materials Only
Daily Production of Material in Batches averaging 1.7 tons	£ 6.90	£12.90	£ 5.10
Production Run Twice Weekly, Batches averaging 6 tons	£ 5.25	£11.00	£ 2.65
Production Run Once per Week, Batches averaging 12 tons	£20.30	£25.90	£18.90
Production Run Once per Month, Batches averaging 50 tons	£33.60	£38.40	£32.20

10 years is used for the freezing and cold store plant, this being a commonly accepted timescale for large plant. However, those parts of the plant capital represented by buildings might reasonably be expected to have an appreciable residual value after this period, further reducing the true cost of freezing and cold storage to some extent.

A second major expense is incurred when frozen materials are used as ingredients, on account of the grinding process needed and the extra capital and labour involved, although the percentage of the cost attributable to this part of the processing is considerably higher where freezing of the pellets is not required and hence where total costs are lower. It should be pointed out, however, that the high cost of grinding of frozen ingredients is due in part to there being a limited range of grinders available in the smaller sizes, since a lower limit is placed on the size of a grinder of sufficient power to handle whole frozen blocks.

In many cases the novel proteins considered in this thesis, where produced on site by the farmer, would not require to be frozen prior to use, the culture output being tailored to seasonal and daily requirements. It should also be noted that silage and blood could be used in the manner suggested for "dry" materials only, since neither of these materials would require mincing prior to mixing (the mincing of fish in the production of fish silage incurs a cost at that stage of the production, as in Section 3.3, and should not be included again at a later stage in the utilisation of this material).

6.4 COSTING OF MOIST PELLETS

6.4.1 A number of diets prepared from ingredients readily obtainable in the UK have been costed according to their raw materials prices as at January 1981 (Table 6.3). To this we may add the appropriate cost of preparation of the moist pellet from Table 6.2 to suggest an approximate cost of using such a moist diet as an alternative to the conventional dry compound diet. This costing can only be done satisfactorily on an individual basis, although where Abernathy type diets are prepared, e.g. using dry ingredients and water only, it should be quite possible to produce moist pellets at £3-£5 per ton in most localities provided that the batch size is kept sufficiently small that refrigeration of a part of the output is not required.

Diets such as those given in Table 6.3 generally produce conversion ratios in the region of 3/1, depending on the water content. In most circumstances moist pellets produce as good or better conversions than dry pellets on a dry weight basis, as indicated in Section 6.6.2. Assuming that conversions are similar to those of dry pellets on a dry weight basis, it is possible to compare the production costs of trout fed on dry pellets and a number of moist dietary formulations, as in the final row of Table 6.3.

The evident sensitivity of moist pellet use to the cost of preparation is much as might be expected. Relatively few fish farmers in Britain seem to have experimented with the use of moist pellets or other home prepared feedstuffs, largely on the grounds that the extra work involved is not justified by the expected economies. The dependence on an often variable supply of fresh feeds is probably also a major factor.

TABLE 6.3 COSTING OF CERTAIN MOIST DIETS AS FED (JAN 1981 PRICES)

	Dry Pellets	Diet No. 1	Diet No. 2	Diet No. 3	Diet No. 4
Cost of Pellets/Ingredients (£'s per ton)	280	160	115	170	150
Cost of Preparation (£'s per ton)	-	5.25	2.65	5.25	5.25
Total Cost (£'s per ton)	280	165	148	175	155
Water Content (%)	7	40	25	40	40
Cost (Dry Weight) (£'s per ton)	300	270	205	290	255
Conversion (Dry Weight Diet/Wet Weight Trout)			1.8/1		
Feed Cost per ton of Trout Produced	£540	£486	£360	£522	£459

Formulation of diets:

Diet 1; Compound meal formulated to combine with 50% wet fish - based on estimate from Edward Baker Ltd (Muir, 1981). As diet No. 8 in Table 6.1.

Diet 2; As diet No. 4 in Table 6.1 with soya meal substituting for cottonseed meal.

Diet 3; As diet No. 5 in Table 6.1, assuming wet fish at £60 per ton.

Diet 4; As diet No. 9 in Table 6.1.

Nonetheless, it appears from Table 6.3 that significant savings may still be made using an Abernathy type moist diet using conventional dry meal ingredients with added water, the materials being easily stored for relatively long periods and preparation being relatively straightforward. Furthermore, recent advances in our knowledge of the nutritional requirements of rainbow trout permit increasingly efficient diets to be formulated. A simple diet may therefore be prepared using readily available ingredients which may be constantly revised using L.P. techniques, according to the changing relative prices of the ingredients, to arrive at a least cost formulation which may not only be significantly cheaper than rigid diets as formulated in Table 6.1, but may also be considerably more stable both as regards price and supply.

6.4.2 The moist diets so far described may be further optimised with relation to price, and a diet was accordingly formulated by means of an L.P. analysis drawing upon a number of common ingredients as listed in Table 6.4. The L.P. analysis followed the same guidelines as those laid down in chapter 2 with the exception that brewers' yeasts, cod liver oil and vitamin binder were included at levels 2%, 2% and 4% respectively to adjust for the inclusion of the binding material in the moist formulation. The results of this L.P. analysis are summarised in Table 6.4, and indicate that a nutritionally adequate diet may be prepared from a relatively small number of materials at a fairly stable ingredients costing of around £250 per ton dry matter. This compares favourably with the cost of most compound "dry" pellets containing usually around 7-8% water.

Moist pellet formulations may also permit the incorporation of wastes and locally produced ingredients in an efficient diet, and may be particularly suitable for the utilisation of those liquid materials which would be unsuitable as a feed by themselves or for inclusion in dry compound pellets. As practical examples of this, further least cost dietary formulations were calculated using fresh blood, white fish silage and earthworms in addition to the common feed ingredients used in Table 6.4. Proposed levels of inclusion of these three test items are indicated in Tables 6.5-7, for prevailing January 1981 prices as shown.

The main limiting amino acid would appear to be the cystine plus methionine combination, and additional ingredients high in these might therefore be sought for the basal ration. It should be noted that the formulations are designed to contribute digestible components to the diet at or above the levels of the trout's requirements, and the crude nutrient content of the diets may be appreciably greater than for many commercially prepared dry diets. There is some justification therefore in stating that the diets formulated may well be superior to commercially compounded pellets, and it may if desired be permissible to reduce the quality criteria used and so to further reduce the ingredients costings in the diets.

By substituting the proposed least cost formulations for those diets costed for use in Table 6.3, taking due regard for the different water contents, it is possible to arrive at some idea of the minimum cost of use of moist pellets that may be achieved.

Tables 6.4-6.7 also indicate the manner in which the optimal formulation changes with varying prices of the basal ingredients, thus indicating the degree of substitutability between these materials. Being of considerable relevance outside the immediate subject of moist

TABLE 6.4. LEAST COST DIETARY FORMULATIONS USING A BASIS OF 10 FREELY AVAILABLE DIETARY INGREDIENTS

INGREDIENT	PRICE AT *1 JAN. 1981. £S/TON D.M.	%INCLUSION (% DRY MATTER)																		
		Price as at Jan.81	HM-40	HM-20	HM-10	HM+10	HM+20	HM+40	WFM-40	WFM-20	WFM-10	WFM+10	WFM+20	WFM+40	BM-40	BM-20	BM-10	BM+10	BM+2-	BM+40
Herring Meal	300	34	55	34	34	29.5	29.5	-	-	-	34	34	34	34	34	34	34	34	34	34
White Fish Meal	297	-	-	-	-	-	-	50	67.5	-	-	-	-	-	-	-	-	-	-	-
Blood Meal	333	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Meat and Bone Meal	185	-	-	-	-	7	7	12	-	-	-	-	-	-	-	-	-	-	-	-
Dried Whey	212	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soya Bean 49%	175	46.5	-	46.5	46.5	55.5	55.5	30.0	-	5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5
Wheat Middlings	125	11.5	37	11.5	11.5	-	-	-	24.5	22.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Dried Brewers Yeast	360	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cod Liver Oil	1,450	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Vitamin/Binder	500	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Ingredients Cost: (£'s per ton d.m.)		254	201	233	244	264	273	279	207	246	254	254	254	254	254	254	254	254	254	254
Protein Content of *2 formulated diet:		55	51.4	55	55	57.6	57.6	56.7	51	51.3	55	55	55	55	55	55	55	55	55	55
Lysine Content (%)		3.8	3.8	3.8	3.8	3.9	3.9	3.9	3.6	3.6	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Cystine + Methionine Content (%)		1.8	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

*1 Converted from prices as sold according to the water content of the item as recorded in Appendix C.
*2 Note that figures for protein, Lysine and Cystine + Methionine content are gross, not digestible.
HM = Herring Meal. (HM-40 = Herring Meal at Jan. 1981 Price - 40%)
WFM = White Fish Meal
BM = Blood Meal
M&B = Meat and Bone Meal
SB = Soya Bean Meal
WM = Wheat Middlings

TABLE 6.4. LEAST COST DIETARY FORMULATIONS USING A BASIS OF 10 FREELY AVAILABLE DIETARY INGREDIENTS

INGREDIENT	PRICE AT *1 JAN. 1981. £S/TON D.M.	Price as at Jan.81	%INCLUSION (% DRY MATTER) HM-40	HM-20	HM-10	HM+10	HM+20	HM+40	WFM-40	WFM-20	WFM-10	WFM+10	WFM+20	WFM+40	BM-40	BM-20	BM-10	BM+10	BM+2-	BM+40
Herring Meal	300	34	55	34	34	29.5	29.5	-	-	-	34	34	34	34	34	34	34	34	34	34
White Fish Meal	297	-	-	-	-	-	-	50	67.5	-	-	-	-	-	-	-	-	-	-	-
Blood Meal	333	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Meat and Bone Meal	185	-	-	-	-	7	7	12	-	-	-	-	-	-	-	-	-	-	-	-
Dried Whey	212	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soya Bean 49%	175	46.5	-	46.5	46.5	55.5	55.5	30.0	-	5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5
Wheat Middlings	125	11.5	37	11.5	11.5	-	-	-	24.5	22.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Dried Brewers Yeast	360	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cod Liver Oil	1,450	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Vitamin/Binder	500	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Ingredients Cost: (£'s per ton d.m.)		254	201	233	244	264	273	279	207	246	254	254	254	254	254	254	254	254	254	254
Protein Content of *2 formulated diet:		55	51.4	55	55	57.6	57.6	56.7	51	51.3	55	55	55	55	55	55	55	55	55	55
Lysine Content (%)		3.8	3.8	3.8	3.8	3.9	3.9	3.9	3.6	3.6	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Cystine + Methionine Content (%)		1.8	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

*1 Converted from prices as sold according to the water content of the item as recorded in Appendix C.
*2 Note that figures for protein, Lysine and Cystine + Methionine content are gross, not digestible.

HM = Herring Meal. (HM-40 = Herring Meal at Jan. 1981 Price - 40%)
WFM = White Fish Meal
BM = Blood Meal
M&B = Meat and Bone Meal
SB = Soya Bean Meal
WM = Wheat Middlings

TABLE 6.4. LEAST COST DIETARY FORMULATIONS USING A BASIS OF 10 FREELY AVAILABLE DIETARY INGREDIENTS (CONT.)

INGREDIENT	M&B-40	M&B-20	M&B-10	M&B+10	M&B+20	M&B+40	SB-40	SB-20	SB-10	SB+10	SB+20	SB+40	WM-40	WM-20	WM-10	WM+10	WM+20	WM+40
Herring Meal	29.5	29.5	29.5	34	34	34	29.5	29.5	29.5	34	55	55	34	34	34	29.5	29.5	29.5
White Fish Meal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Blood Meal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Meat and Bone Meal	7	7	7	-	-	-	-	7	7	7	-	-	-	-	-	7	7	7
Dried Whey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soya Bean 49%	55.5	55.5	55.5	46.5	46.5	46.5	55.5	55.5	55.5	46.5	-	-	46.5	46.5	46.5	55.5	55.5	55.5
Wheat Middlings	-	-	-	11.5	11.5	11.5	-	-	-	11.5	37	37	11.5	11.5	11.5	-	-	-
Dried Brewers Yeast	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cod Liver Oil	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Vitamin Binder	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Ingredients Cost: (£'s per ton d.m.)	250	252	253	254	254	254	216	235	245	254	254	254	248	251	253	254	254	254
Protein Content of *2 formulated diet:	57.6	57.6	57.6	55	55	55	57.6	57.6	57.6	55	51.4	51.4	55	55	55	57.6	57.6	57.6
Lysine Content (%)	3.9	3.9	3.9	3.8	3.8	3.8	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.9	3.9	3.9
Cystine + Methionine Content (%)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8

TABLE 6.4. LEAST COST DIETARY FORMULATIONS USING A BASIS OF 10 FREELY AVAILABLE DIETARY INGREDIENTS (CONT.)

INGREDIENT	M&B-40	M&B-20	M&B-10	M&B+10	M&B+20	M&B+40	SB-40	SB-20	SB-10	SB+10	SB+20	SB+40	WM-40	WM-20	WM-10	WM+10	WM+20	WM+40
Herring Meal	29.5	29.5	29.5	34	34	34	29.5	29.5	29.5	34	55	55	34	34	34	29.5	29.5	29.5
White Fish Meal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Blood Meal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Meat and Bone Meal	7	7	7	-	-	-	-	7	7	7	-	-	-	-	-	7	7	7
Dried Whey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soya Bean 49%	55.5	55.5	55.5	46.5	46.5	46.5	55.5	55.5	55.5	46.5	-	-	46.5	46.5	46.5	55.5	55.5	55.5
Wheat Middlings	-	-	-	11.5	11.5	11.5	-	-	-	11.5	37	37	11.5	11.5	11.5	-	-	-
Dried Brewers Yeast	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cod Liver Oil	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Vitamin Binder	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Ingredients Cost: (£'s per ton d.m.)	250	252	253	254	254	254	216	235	245	254	254	254	248	251	253	254	254	254
Protein Content of *2 formulated diet:	57.6	57.6	57.6	55	55	55	57.6	57.6	57.6	55	51.4	51.4	55	55	55	57.6	57.6	57.6
Lysine Content (%)	3.9	3.9	3.9	3.8	3.8	3.8	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.9	3.9	3.9
Cystine + Methionine Content (%)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8

TABLE 6.5 % INCLUSION OF FRESH BLOOD* TO GIVE LEAST COST DIETARY FORMULATIONS AT:- (£s PER TON DRY WEIGHT)

	1981 Jan. Price	0	33	66	99	133	167	200	233
Herring Meal	300	39	39	39	39	36.5	34.0	34.0	34.0
White Fish Meal	297	-	-	-	-	-	-	-	-
Blood		41	41	41	41	35.7	-	-	-
Meat and Bone Meal	185	-	-	-	-	-	-	-	-
Dried Whey	212	2	2	2	2	-	-	-	-
Soya Meal 49%	175	10	10	10	10	19.3	46.5	46.5	46.5
Wheat Middlings	125	-	-	-	-	0.5	11.5	11.5	11.5
Dried Brewer's Yeast	360	2	2	2	2	2	2	2	2
Cod Liver Oil	1,450	2	2	2	2	2	2	2	2
Vitamin Binder	500	4	4	4	4	4	4	4	4
Cost of Diet		194	207	221	235	247	254	254	254

* on dry weight basis, assumed nutritionally similar to blood meal.

TABLE 6.6 % INCLUSION OF FISH SILAGE* TO GIVE LEAST COST DIETARY FORMULATIONS AT:- (£s PER TON DRY WEIGHT)

	1981 Jan. Price	180	240	300	360	420
Herring Meal	300	-	-	34	34	34
White Fish Silage		67.5	64.5	-	-	-
Blood Meal	333	-	-	-	-	-
Meat & Bone Meal	185	-	-	-	-	-
Dried Whey	212	-	-	-	-	-
Soya Meal 49%	175	-	5.0	46.5	46.5	46.5
Wheat Middlings	125	24.5	22.5	11.5	11.5	11.5
Dried Brewer's Yeast	360	2	2	2	2	2
Cod Liver Oil	1,450	2	2	2	2	2
Vitamin Binder	500	4	4	4	4	4
Cost of Diet		208	248	255	255	255

* on dry weight basis, assumed nutritionally similar to white fish meal.

TABLE 6.7 % INCLUSION OF L. TERRESTRIS* TO GIVE LEAST COST DIETARY FORMULATIONS AT:- (£s PER TON DRY WEIGHT)

	1981 Jan. Price	100	125	150	175	200	225	250	275	300
Herring Meal	300	-	-	-	-	-	-	-	-	34
White Fish Meal	297	-	-	-	-	-	-	-	-	-
Blood Meal	333	-	-	-	-	-	-	-	-	-
Meat & Bone Meal	185	-	-	-	-	-	6.5	6.5	6.5	-
Dried Whey	212	-	-	-	-	-	-	-	-	-
Soya 49%	175	-	-	-	37.5	37.5	44.0	44.0	44.0	46.5
Wheat Middlings	128	16.0	16.5	16.5	20.0	20.0	15.0	15.0	15.0	11.5
Dried Brewer's Yeast	360	2	2	2	2	2	2	2	2	2
Cod Liver Oil	1,450	2	2	2	2	2	2	2	2	2
Vitamin Binder	500	4	4	4	4	4	4	4	4	4
L. Terrestris	-	76	75.5	75.5	34.5	34.5	26.4	26.4	26.5	-
Cost		152	171	190	207	215	223	230	236	254

* On dry weight basis.

diets, substitution and competition between these items is discussed further in chapter 7.

6.5 STORAGE AND SPOILING OF INTERMEDIATE MOISTURE FOODS

Semi-moist animal foods generally contain moisture levels of between 20% and 50%. Micro-organisms responsible for the spoilage of food require substantial levels of water in order to grow, and therefore reducing the water content of the feed effectively slows the rate of food spoilage. (In "dry" compound feeds the water content is generally in the region of 10% or less, which virtually halts microbial activity and allows safe storage periods for up to a year or more if stored under dry conditions). The effective concentration of water in a substance available for microbial growth is usually measured as the water activity, defined as:

$$Aw = \frac{Ps}{Po} = \frac{Nw}{Nw + Ns}$$

where Aw is the water activity

Ps is the vapour pressure of the water in the food

Po is the vapour pressure of pure water at the same temperature

Nw is moles of water, and

Ns is moles of solute.

This formula enables the water activity of a solution of food of known composition to be calculated. The water activity is of major importance to the use of intermediate moisture foods in the manner in which it affects microbial spoilage. Foods with very similar moisture levels may have widely differing water activities, depending upon the degree to which the water is free or bound to the food components, and many intermediate moisture foods with relatively high moisture contents may have their water activity reduced by the addition of salt or sugar to increase the solution strength of the food moisture. Note, however, that this would tend to mitigate against the advantages of osmotic balance claimed for intermediate moisture foods in Section 6.2.2.4.

The majority of important food spoilage bacteria will not grow at water activities of less than 0.90. Some halophilic bacteria and osmophilic yeasts may grow at water activities as low as 0.75 (Potter, 1970), but these are not generally important causative agents of food spoilage. Molds, however, may continue to grow well at water activities as low as 0.80 and may continue to grow at a reduced rate at water activities as low as 0.70. This level corresponds to a total moisture content of well below 20% in many foods, however, and such foods will resemble the proprietary "dry" compounds in many respects. Long term inhibition of mold growth would therefore generally require further measures, such as freezing or the addition of an anti-mycotic agent (for instance, Potassium Sorbate at levels of 0.8% (McKee and Westgate, 1973)).

Moist pellets as related to trout culture would normally have moisture levels of around 25% to 40%. It is not possible to state categorically what such water contents would correspond to in terms of the water activities, but in general these would tend to fall in the range 0.75 and 0.97, which would of course result in a very wide range of shelf stabilities. Without specific measurements of the water activity of the pellet, it is therefore unfortunately not possible to state the expected period of storage over which the product would remain acceptable without further means of preservation. In general, moist pellets will usually remain in good condition for 3-4 days without the addition of extra preservatives. This may be further extended by storage at low temperatures or by reduction of the pH to less than 5.0 (Leistner and Rodel, 1976).

Should the water activity be known (or measured) it would be possible to estimate the acceptable storage period, although bearing in mind that other factors such as pH, Eh and the presence or otherwise of natural antibiotics within the ingredients will also be of influence. Further information on this subject may be found if required in "Intermediate Moisture Foods" (Davies, Birch and Parker, 1976); "The Stability of Intermediate Moisture Foods with Respect to Micro-organisms" (Leistner and Rodel, 1973); "The Microbial Stability of Intermediate Moisture Foods with Respect to Yeasts" (Tilbury, 1973); and "The Stability of Intermediate Moisture Foods with Respect to Mould Growth" (Seiler, 1973).

In addition to microbial deterioration, intermediate moisture foods may undergo slow chemical changes. Dairy products are susceptible to changes arising on account of the high lactose content, while fishmeals may be unstable on account of the ribose content of the mucleic acid (Williams, 1976). A further important consideration with respect to trout feedstuffs is that lysine rich foods may be susceptible to loss of lysine (Frangne and Adrian, 1962). While moist pellets may therefore be stored for short periods without further means of preservation, the gradual reduction in the nutritive qualities makes it beneficial to use these materials as soon as possible after preparation.

6.6 SUMMARY AND CONCLUSIONS

Moist pellets, having moisture contents of between 25% and 40%, may be prepared relatively simply from mixed wet and dry ingredients or from dry ingredients only with added water. Many such moist diets have been formulated and in a number of cases they have proved to be more acceptable to trout and other fish than are commercially prepared dry compound pellets.

In certain ways, moist pellets combine many of the relative advantages of wet feeds and dry pellets. Wet feeds, as used recently in Denmark for instance, may not only be cheaper to use but also frequently produce faster trout growth than dry feeds (Bregnballe, 1963). Against this, dry pellets are more convenient to use, reduce labour costs, wastage and pollution loadings, may be of more consistent quality and have a relatively stable supply. Moist pellets can combine all or most of these relative advantages, as well as giving the farmer individual choice as to pellet size, protein content and the inclusion of additives such as pigments or medicinal compounds. They may thus conveniently be used to exploit locally available "waste" materials and/or feedstuffs cultured on site.

The relative disease and dietary problems resulting from the use of wet, moist and dry feeds are still far from clear. While wet foods may undoubtedly introduce pest organisms directly, such disease organisms may be largely controlled by the inclusion of selected drugs in the wet diets. Other dietary disorders may arise as a result of the food type, while organoleptic properties of the fish flesh may also be affected. Ghittino (1979a) states that fish fed on dry diets give a consistently acceptable product, while fish fed on traditional wet diets tend to be less consistent, richer in fat, softer-fleshed and having a disagreeable "hatchery" flavour. This does not appear to be a widely held view, however, and off-flavours may be present in fish fed a wide variety of diets and is possibly related more to the water quality of the tanks.

Moist pellets are not as suitable for use with automatic feeding systems as are dry pellets, their softer consistency making them prone to clog the apparatus. Screw augurs, belt conveyors and some vibrating disc type feeders may nonetheless be used satisfactorily. Wastage may be much reduced if suitable binders are used when preparing the pellet. A study has been conducted on the suitability of various binders for this purpose at the White Fish Authority culture unit at Hunterston. (Thain and Urch, 1973).

Despite the fact that the ingredients cost of moist diets is frequently considerably cheaper than the cost of complete commercially prepared diets, Stevenson (1980) suggests that there is an increasing tendency to use ready pelleted dry feeds on account of their simplicity of use. There would appear, however, to be significant economic advantages in the use of moist pellets where a regular supply of cheap materials is readily available and the necessity of freezing can be avoided. Ghittino (1979b) states that he feels that a return to moist diets may be conceivable in fish farming on account of their lower costs in some circumstances and their wide acceptability to most cultured fish species. This sentiment is echoed by Webber and Huguenin (1979) who indicate that recent developments involving the use of fermentation techniques have resulted in high quality moist rations with a shelf life of about 30 days at ambient temperatures, thus greatly relieving the problem of high-cost storage methods (freezing and cold-store) which have so far virtually excluded the use of such diets where fresh wet ingredients cannot be obtained on an almost daily basis.

Documented use of moist pellets in the UK is rather limited, although it is very probable that a number of fish farmers have experimented individually with locally available waste or cheap materials without publishing their findings. However, the White Fish Authority pilot scale turbot and Dover sole culture unit at Hunterston has published a number of interesting reports concerned with the use of moist pellets in flatfish culture, for which they have proved highly suitable. It has further proved possible to mix a wet fish component with a premixed meal component specifically formulated to complement the wet part of the diet and prepared by a commercial feedstuff manufacturer (W.F.A., 1980).

Moist pellets could prove particularly useful in the exploitation of liquid materials - e.g. blood, fish silage, activated sewage sludge, etc - unsuitable for inclusion in dry feeds unless further reduced to meal form, which additional expense would negate any economic benefits to be derived from the use of these materials.

Cost of moist pellet preparations is fairly stable (Section 6.4.2), although sensitive to price changes in the major dietary ingredients which are not easily substitutable, e.g. herring meal. Commercial pellets are also sensitive to price changes of such items, although to a lesser extent on account of the wider range of ingredients called upon.

The cost of preparation of moist pellets is fairly low unless grinding of frozen blocks of raw material and/or freezing and cold storage of the pellets is required. This would tend to recommend the use of moist pellets primarily to those farms with a supply of cheap materials locally, and above all regularly available, although new developments in the prevention of spoilage reported by Webber and Huguenin may be of benefit to those farms not in such a situation. Practise and experience in moist pellet formulation could possibly enable preparation costs to be further reduced, particularly with regard to the capital cost of machinery. At the present time, choice of machinery is rather restricted, and the capacities of those machines costed may in some instances be well in excess of requirements.

There would appear therefore to be a considerable case for the utilisation of moist pellets, whether or not to take advantage of a cultured or cheap waste material. The prospects may well become increasingly attractive in future as knowledge, experience and choice of materials and machinery increases. The economic attractiveness might also be enhanced by the setting up of co-operatives to optimise the use of capital machinery and to share the cost of formulating least cost diets at prevailing prices.

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CHAPTER 7

Technological economic assessment

7.1 PURPOSE OF TECHNOLOGICAL ECONOMIC ASSESSMENT

The purpose of this thesis as laid down in the preface is to explore means of reducing or stabilising feed and feed related costs in trout farming in the United Kingdom. The text has attempted to achieve this by investigating the technical and economic aspects relating to the development of new feed ingredients and new feed types, examining each case individually according to a loosely defined pattern.

There is however a great diversity to be found in the UK trout culture industry, and in order for this thesis to be of value outside the restricted range defined by specific examples cited there is at this stage a requirement for an overview of the options available and of the likely consequences in the general context of the economic climate pertaining to the UK feedstuffs industry, serving both as a concise and practical guide to the trout farmer and providing also a framework of projections as to the future development of the industry.

7.2 THE ECONOMICAL USE OF EXISTING COMPOUND FEEDS

The economical use of feedstuffs is governed by a large number of interrelated factors. Some of these are at least partially within the culturist's control, and are summarised below:

- Trout grow faster and more efficiently at certain stages of their development. The stocking policy adopted and the size profile of the stock, in particular in size at harvest, is therefore of prime importance in achieving optimum use of feeds. This must however be reconciled with the size profile of the market.

- Growth efficiency may be improved by manipulation of the environment, such as control of water flow and quality or temperature. The benefits in growth efficiency must be balanced against the cost incurred in manipulating the environment.
- Growth efficiency is affected by regularity of feeding, and demand feeding, automatic feeding and hand feeding all have merits depending on the stage of development of the fish and the culture system in use.

The optimal manipulation of all environmental factors under the farmer's control can be included in the general context of good fish husbandry, which should be the aim of every trout farm regardless of the feeding regime in use. These subjects are regarded as being outside the context of this thesis as embodied in the title, and reference is made to them as part of the background only in the introductory chapter on account of their relevance to other factors more central to the thesis, which concerns itself primarily with the manner in which the farmer may reduce costs by the development of new diets.

7.3 THE DEVELOPMENT AND USE OF ALTERNATIVE FEEDSTUFFS

The development of alternative feedstuffs embraces two distinct concepts - the development of new feed ingredients and the development of new feed types. The two concepts are nonetheless frequently mutually interdependent.

7.3.1 Development of alternative feed ingredients: This thesis has considered a number of food materials as alternatives to the common meal ingredients of compound pellets, to be used either as replacement materials in the formulation of such pellets or as a simple feed on their own. The potential value of these items varies according to their proposed manner of use, and Table 7.1 therefore attempts to summarise the value of these items under specified conditions of use, contrasting this value with either the cost of the material where readily available for purchase or the estimated cost of production of the material. Reference is made to the appropriate sections in the text to define the conditions under which the material is evaluated.

The table is divided into three sections from which a number of general observations may be made concerning the direction of future progress in the development of new ingredients.

Section 1 groups wet animal materials which may be fed either alone or in simple combination with each other or with vitamin binder additives. Many of these are also the raw materials for the ingredients of the dry compound pellets against which they are compared, and it is significant that as a group the maximum estimated value of the materials is usually close to their cost price. There is inevitably competition between the wet raw material and the dry meal product, and the price of the meal is therefore restrained, by competition with its own raw material as well as by competition with similar meal products, at a level at which it is able under most circumstances to oust the wet material on account of the greater adaptability of meal and its suitability for use in the nutritionally

TABLE 7.1. SUMMARY OF ALTERNATIVE FEEDS

SECTION	MATERIAL	POTENTIAL	% DRY MATTER	DATE	COST £'s	MANNER OF USE	MAX. VALUE	MANNER OF EVALUATION
SECTION 1	Industrial fish	Very large	~ 25%	Jan 1980	~ £50	Whole diet *1	< £60	Evaluated as a whole diet with added vitamins binders only, costed as in Section 4.3.5.
	Industrial fish	Very large	~ 25%	Jan 1981	~ £50	Moist diet ingredient	< £75	Evaluated as protein competitor for fish meal, as in Appendix J.
	Shellfish offals and mussels	Small	~ 10 - 15% (Exclusing shells)	Jan 1981	Highly variable	Moist diet ingredient	Highly variable up to £40	Evaluated as substitute for industrial fish in moist diet costed in Section 6.
	Krill meal	Very large	~ 90%	Jan 1980	Potentially £200 - £300	Dry or moist diet ingredient	~ £211	Evaluated by L.P. Model summariesed in Appendix H assuming 90% digestibility.
	Mixed meat offals	Moderate - Large	~ 25%	Jan 1980	£70 - £110	Whole diet *1	< £100	Evaluated as a whole diet with added vitamins/ binders only, costed as in Section 4.5.8.
	Mixed meat offals	Moderate - Large	~ 25%	Jan 1980	£70 - £110	Supplement to dry diet	< £105	Evaluated as a supplement to a low protein dry diet, costed as in Section 4.5.8.
	Blood	Small - Moderate	~ 10%	Jan 1981	£0 - £30	Moist diet ingredient	< £17	Evaluated as protein competitor for blood meal in moist diet, as in graph 7.6.
	Seal meat	Small	~ 25%	Jan 1980	Potentially £200	Whole diet *1	< £100	Evaluated as substitute for mixed meat offals costed in Section 4.5.8.
SECTION 2	"Pruteen" S.C.P.	Very Large	92.51	Jan 1981	£240	Dry or moist diet ingredient	< £220	Evaluated on the basis of protein analysis as in Section 5.4.
	A.S.C.P. meal	Very Large	~ 92%	Jan 1981	>> £106	Dry diet ingredient	~ £106	Evaluated by L.P. model summarised in Appendix H, assuming 90% digestibility.
	Distiller's dried residues	Moderate	~ 92%	Jan 1980	£114	Dry or moist diet ingredient	~ £114	Evaluated on the basis that this material may be used in trout feed formulations at this price.
	Aquatic weed meals	Moderate	~ 90%	Jan 1980	>> £70	Dry diet ingredient	£60 - £70	Evaluated by L.P. model summarised in Appendix H, assuming 90% digestibility.
SECTION 3	Worms - L. terrestris	Moderate	~ 27%	Jan 1980	> £48	Dry or moist *2 diet ingredient	£65	Evaluated by L.P. model summarised in Appendix H, assuming 90% digestibility.
	Worms - L. terrestris	Moderate	~ 27%	Jan 1981	> £48	Moist diet ingredient	< £75	Evaluated as ingredient of moist diet by L.P. analysis as in graph 7.8.
	Worms - E. foetida	Moderate	~ 25%	Jan 1980	> £48	Dry or moist *2 diet ingredient	£59	Evaluated by L.P. model summarised in Appendix H, assuming 90% digestibility.
	Muscus domestica	Small - Moderate	~ 20%	Jan 1980	> £100	Dry or moist *2 diet ingredient	£41	Evaluated by L.P. model summarised in Appendix H, assuming 90% digestibility.
	Talitrus saltator	Small - Moderate	~ 14%	Jan 1980	?	Dry or moist *2 diet ingredient	£21	Evaluated assuming similar nutritional qualities to Gammarus in Appendix H.
	Aquatic detritivores, e.g. Daphnia, Tubifex and Chironomus larvae	Moderate	10 - 16%	Jan 1980	> £35	Dry or moist *2 diet ingredient	£20 - £35	Evaluated by L.P. model summarised in Appendix H, assuming 90% digestibility.
	Termites	Small	56%	1979 - 1980	Very high	Any	~ £100	Estimated on the basis of proteing analysis as in Section 6.5.4.

*1 With Added Vitamin/Binder Materials Only

*2 Evaluated on basis of competition with dry meals, but would of course require prior dewatering before they could be used in dry compound feeds.

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*1 With Added Vitamin/Binder Materials Only

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efficient commercially compounded pellets. (Note that the values quoted in column 7 of Table 7.1 are likely maximum values and depend on favourable circumstances which may not be entirely applicable to many real situations).

The competition between materials may however force a price at which the reduction process becomes uneconomic (hence the many nutritionally adequate products that are not available as meals) or only marginally attractive (as appears to be the case with blood meal). The mutual interdependence of materials results in a dynamic price structure, as a change in the status of one material affects the price and hence also the availability of and demand for competing materials, providing the logical and economic justification for an equally dynamic technique of feed formulation.

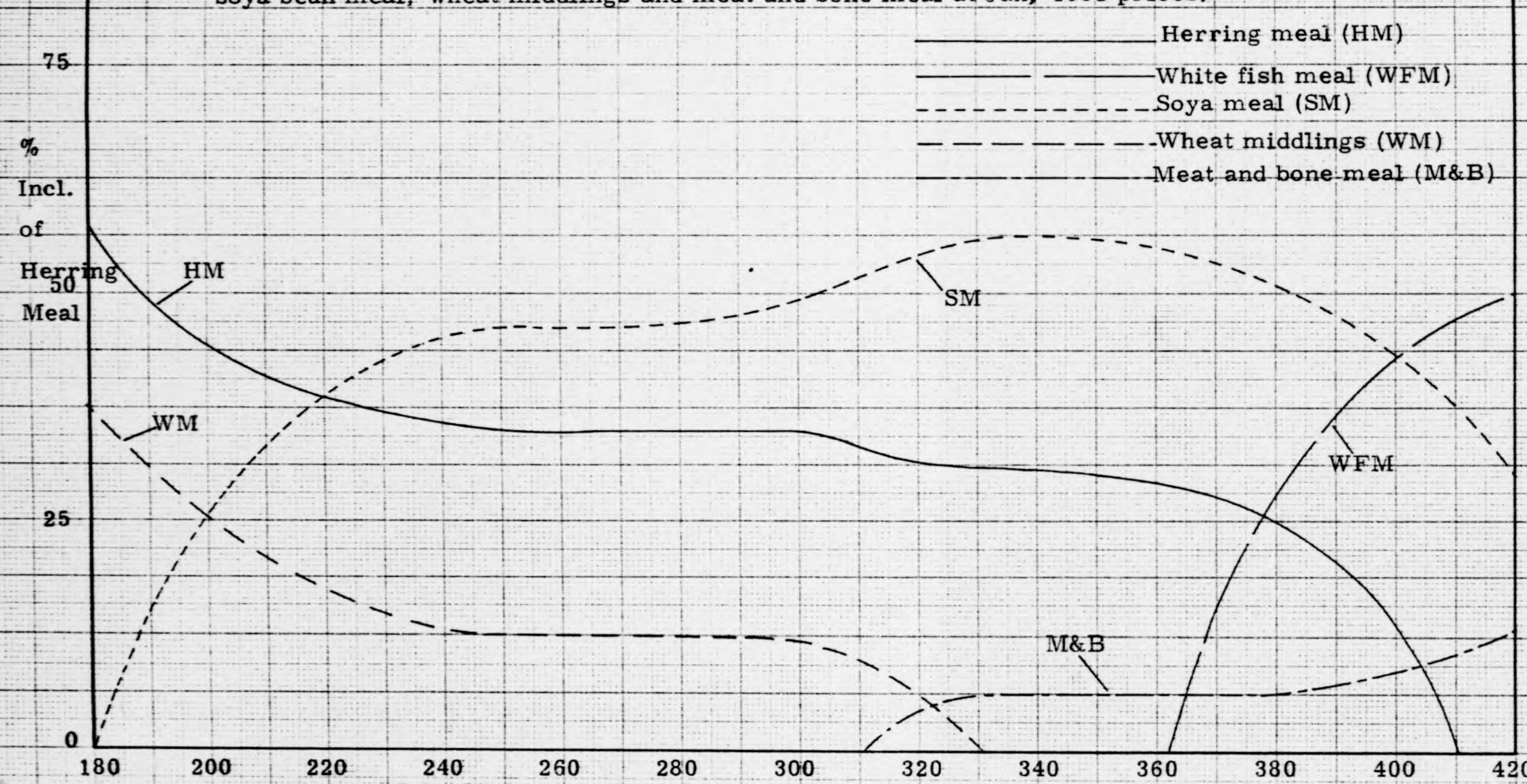
On account of these factors, it is unlikely that a fish farm would benefit from a switch from dry compound pellets to a feed based on the wet raw materials unless it was in a favoured position to obtain supplies at less than the open market value. These situations may occur where producers of a prime product (e.g. meat or table fish) have no local market for their offals and industrial catches or by-products, and where the cost of transport or the small scale of operation restricts their access to markets further afield. These circumstances are more likely however to benefit relatively small producers since the availability of large quantities of material is itself a major factor in the development of access to more distant markets.

Blood would appear to be a possible exception to the above, largely on account of its high costs of drying and the low digestibilities reported for blood meal. Its high water content would not prohibit its use in moist dietary formulations, although the level of inclusion would necessarily be fairly low, and its value in this respect would be highly dependent on the digestibility of unprocessed blood on which further information would be desirable. Seal meat and shellfish offals might similarly be useful locally because the small quantities available in most cases are insufficient to justify the development of other markets, but these same quantities also greatly limit their usefulness to fish farming in the general context.

In the short term therefore there are unlikely to be significant benefits to the trout culture industry resulting from a change of use of pellets to the use of non-compounded fresh diets, such benefits as might be achieved accruing largely to small producers with favourable access to the fresh materials. A reduction in price of any of the major items would be far more consequential, but since the supply and processing of many of these are already operating at low profit margins there is little current prospect of this. Krill meal could possibly have an impact if technological improvements result in cheaper harvesting or if a high-priced human market is developed for the tail meats thus indirectly subsidising meal production. Any effect that this could have would nonetheless be highly dependent on the structure of the krill fishery. Provided that there was no tendency towards a monopoly, competition in the industry would almost certainly reduce profit margins to levels resembling those in the other meal reduction industries, and could result in a price at which krill meal might begin to replace fishmeal in compound diets on a large scale.

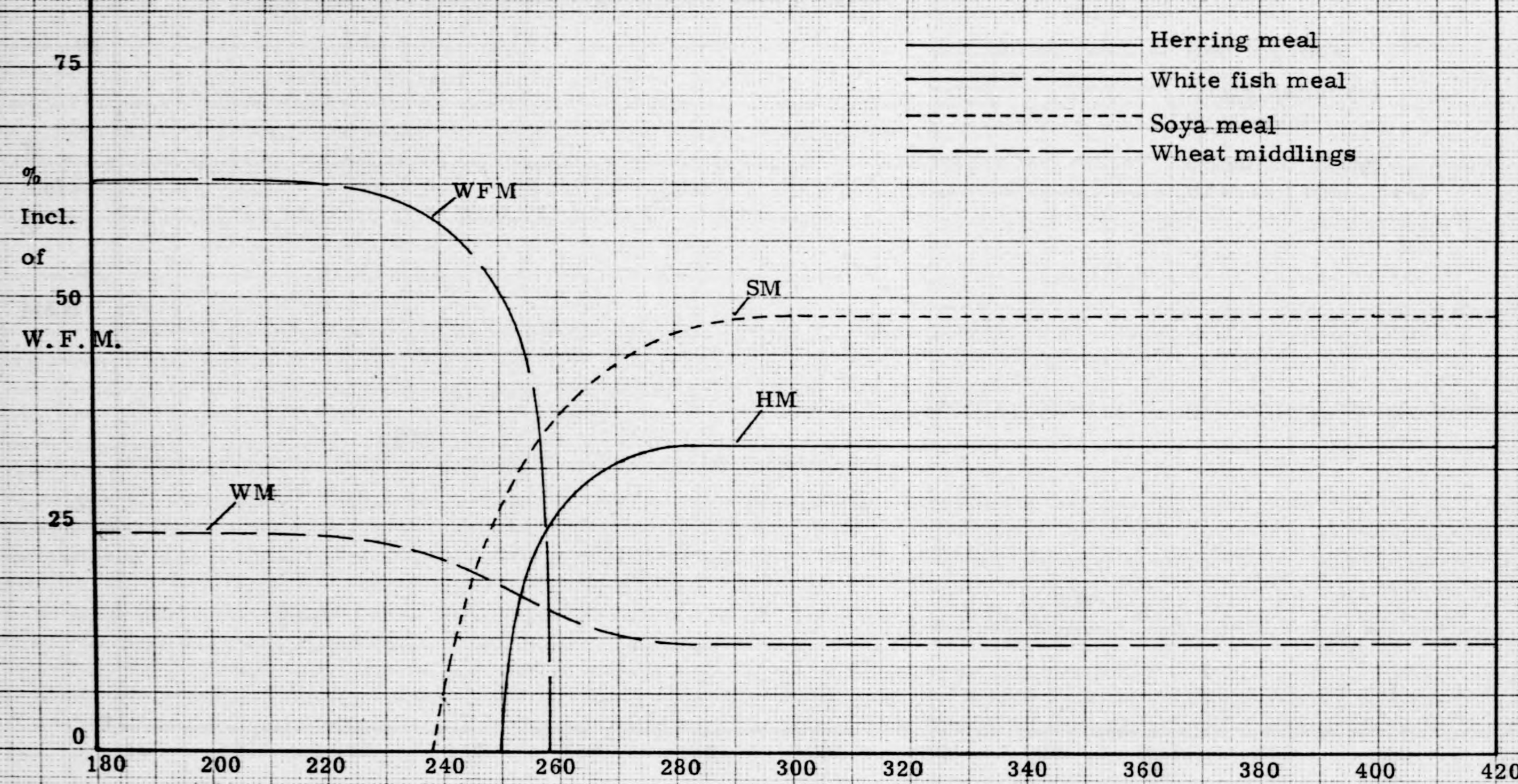
Substitutability between the various materials listed is of prime importance in determining the extent of competition and hence the interdependent price structure. A series of graphs (graphs 7.1-7.8) are derived from the linear programming least cost model used in the formulation of moist diets in chapter 6 and illustrate the degree

Graph 7.1. % Inclusion of herring meal at varying price against white fish meal, soya bean meal, wheat middlings and meat and bone meal at Jan, 1981 prices.



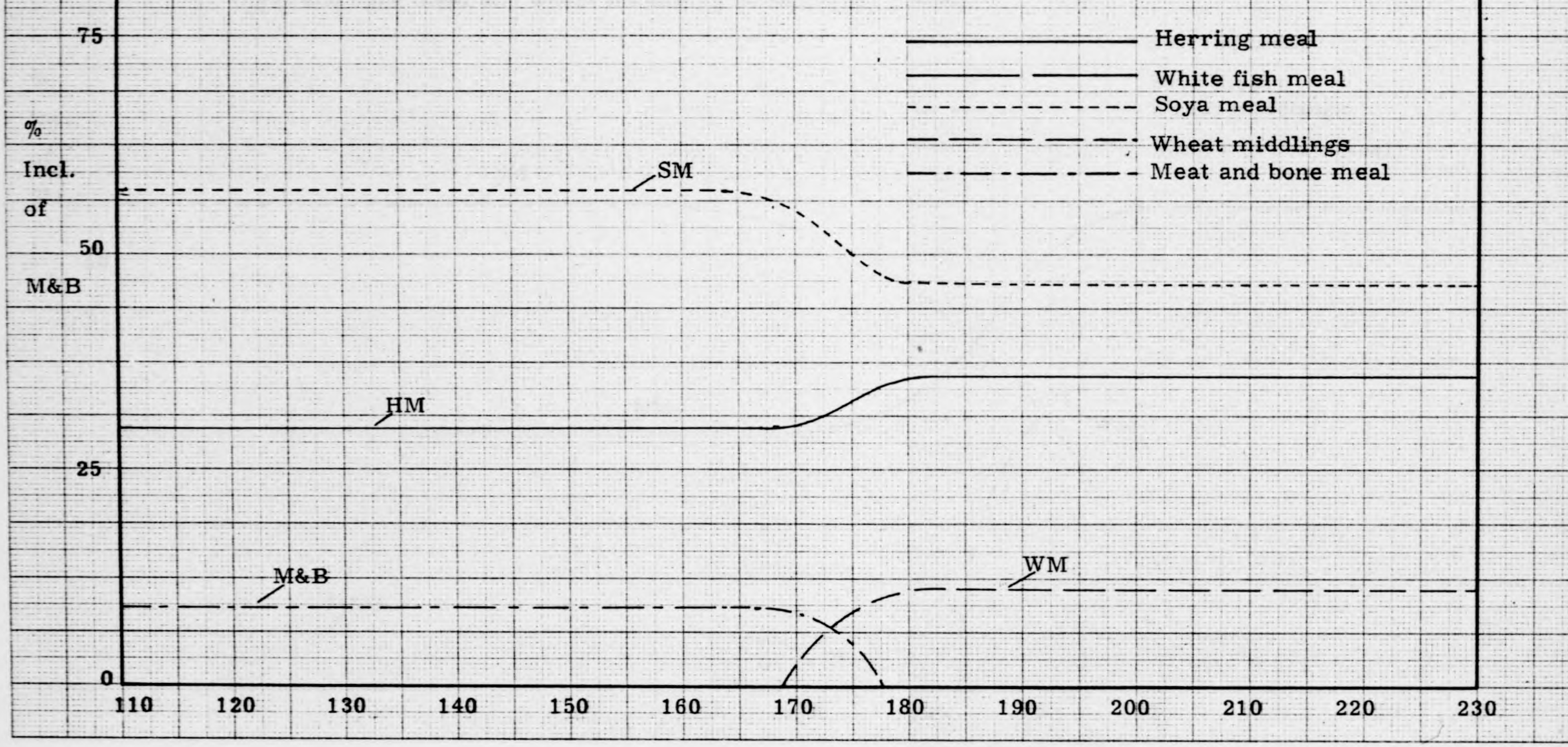
Price of herring meal (£'s per ton dry weight).

Graph 7. 2. % Inclusion of white fish meal at varying price against herring meal, soya bean meal and wheat middlings at Jan. 1981 prices.



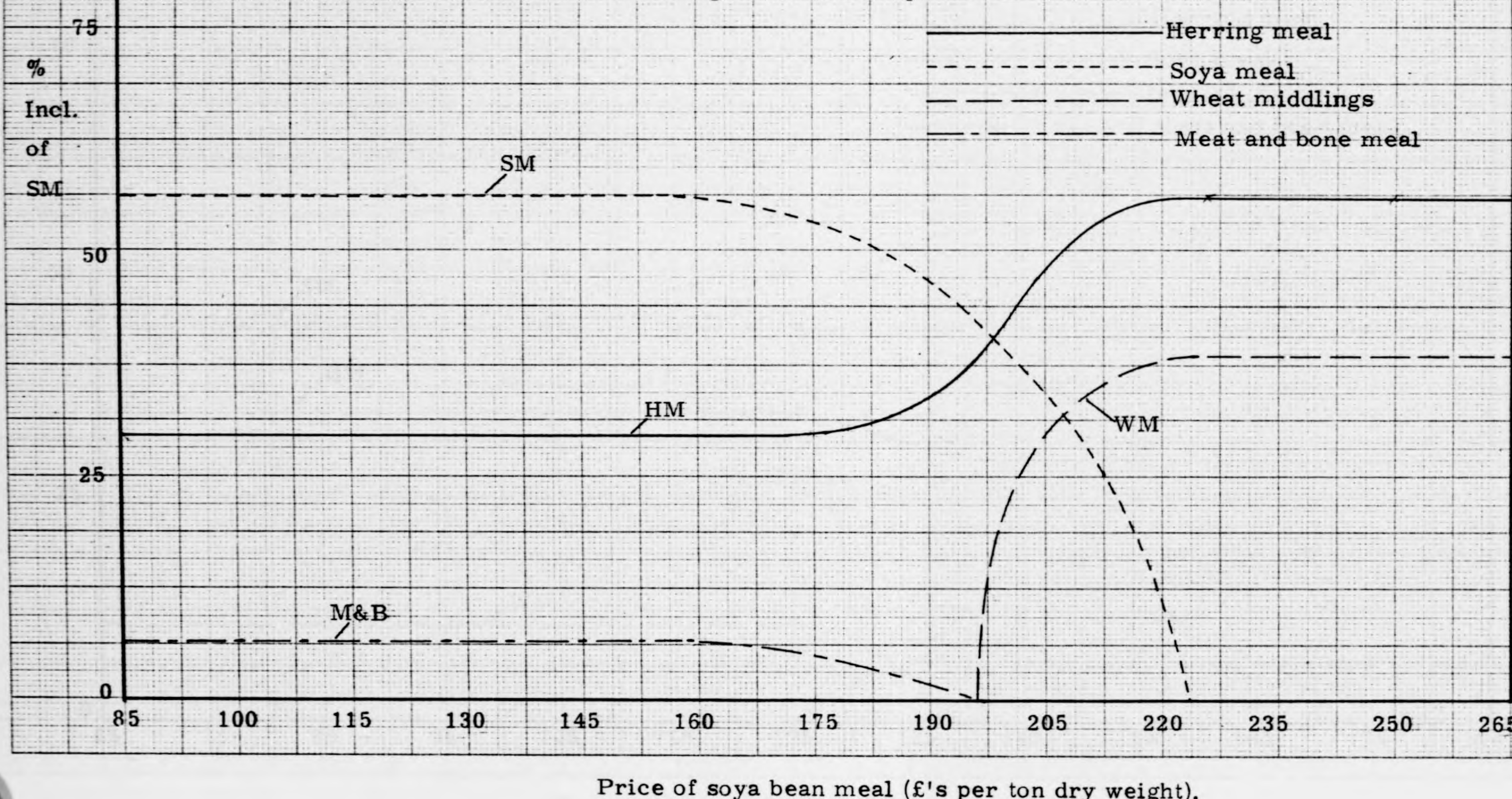
Price of white fish meal (£'s per ton dry weight).

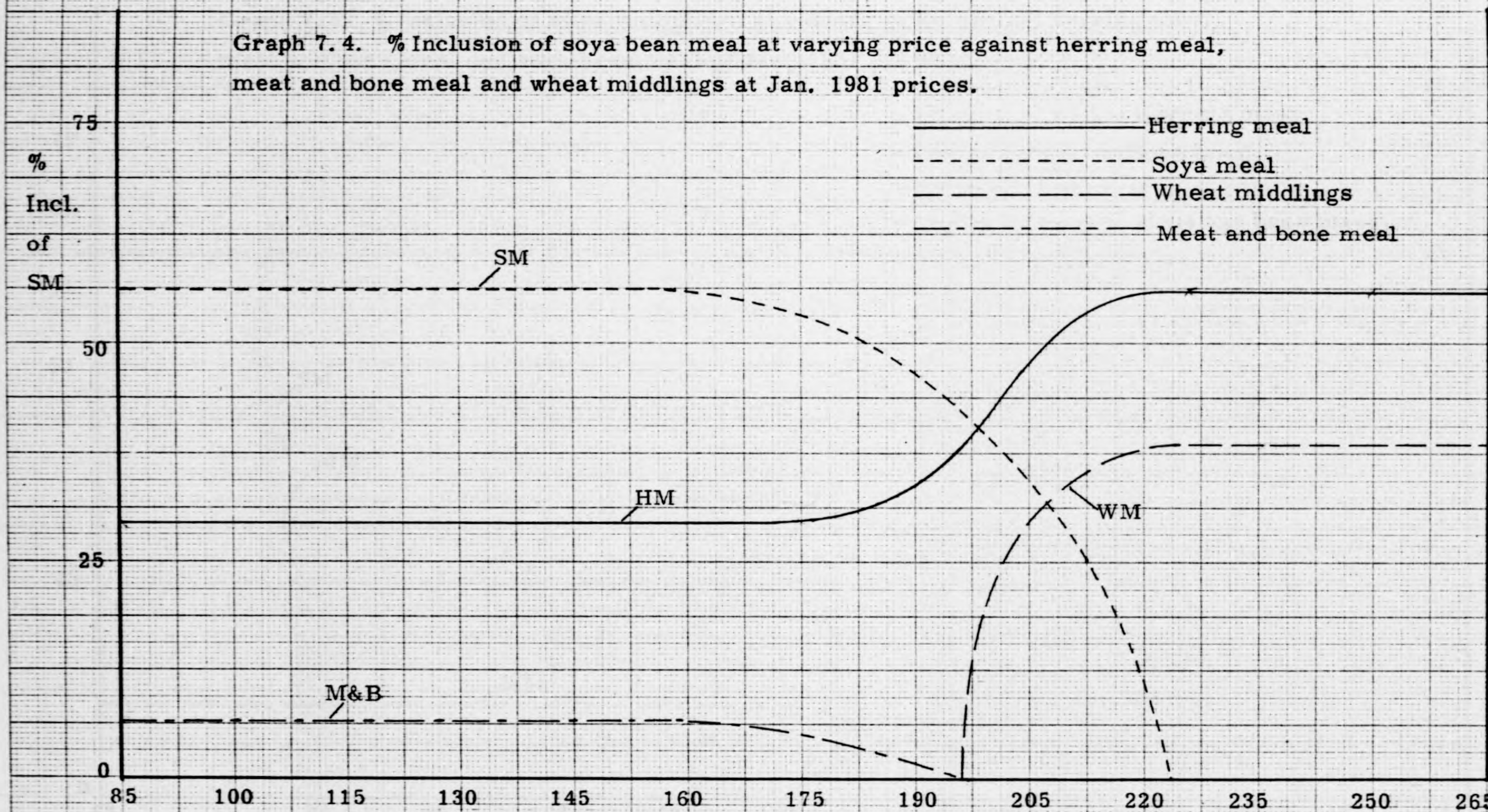
Graph 7.3. % Inclusion of meat and bone meal at varying price against herring meal, soya meal and wheat middlings at Jan. 1981 prices.



Price of meat and bone meal (£'s per ton dry weight).

Graph 7. 4. % Inclusion of soya bean meal at varying price against herring meal, meat and bone meal and wheat middlings at Jan. 1981 prices.

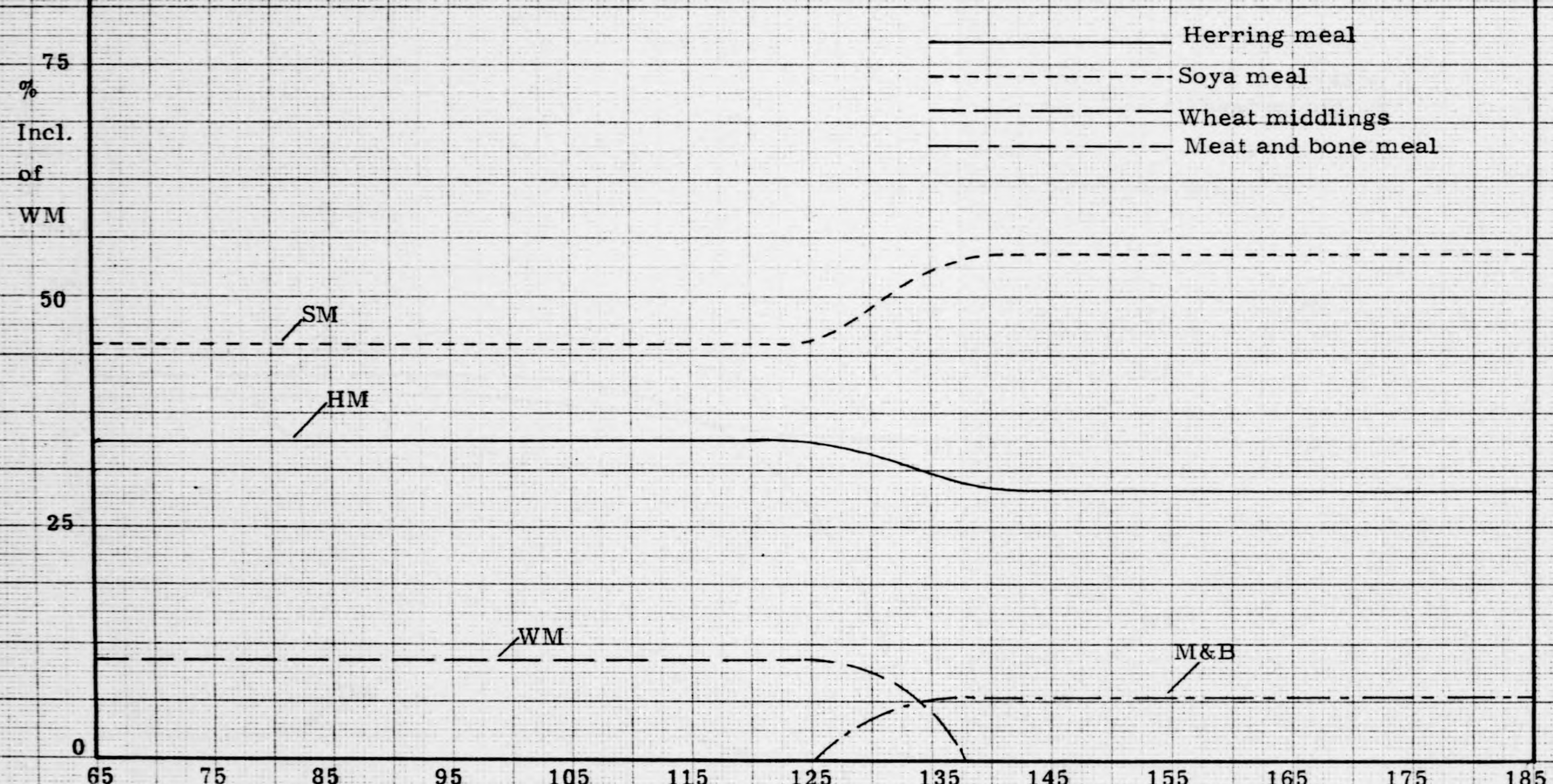




Graph 7.4. % Inclusion of soya bean meal at varying price against herring meal, meat and bone meal and wheat middlings at Jan. 1981 prices.

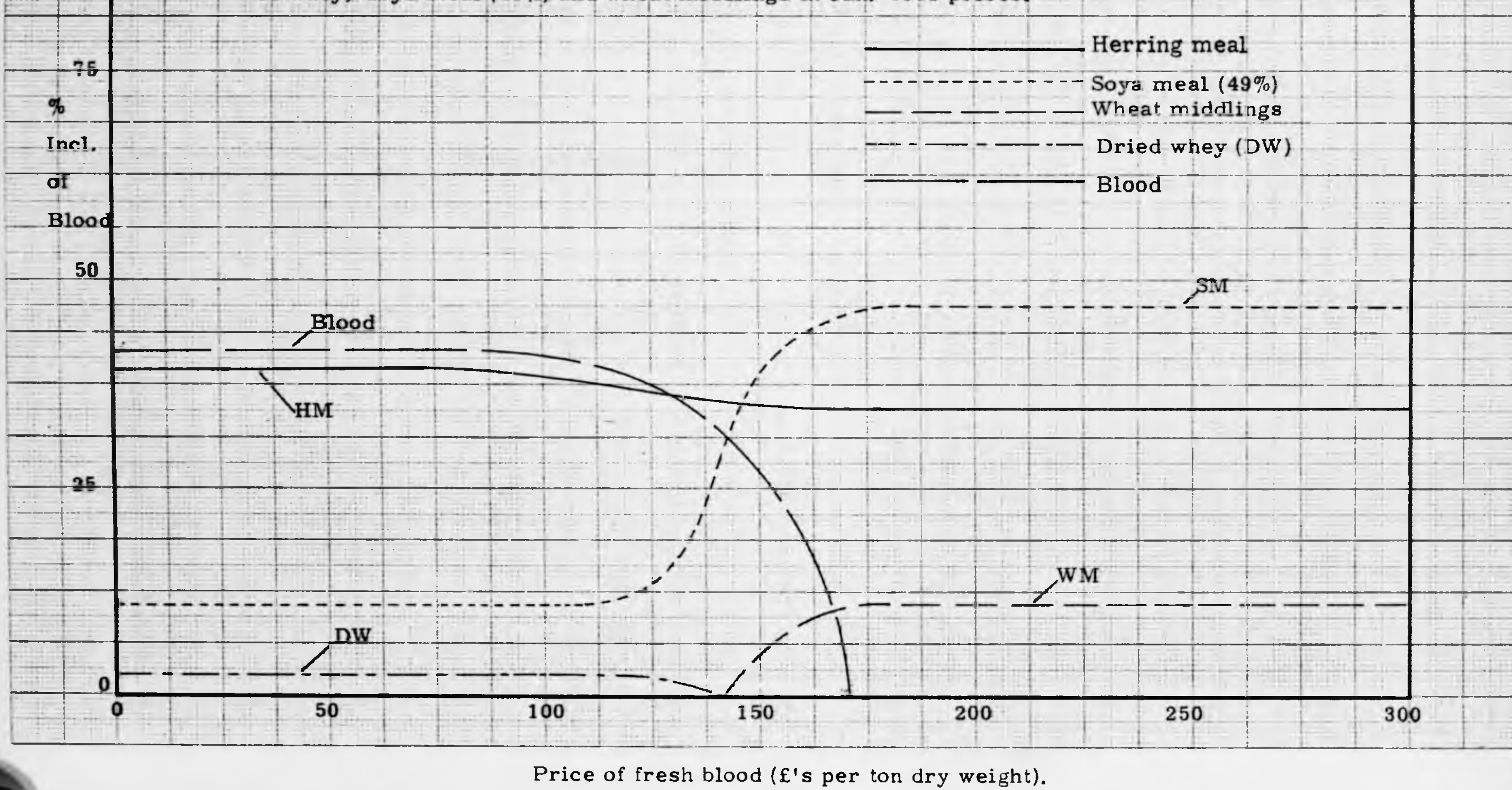
Price of soya bean meal (£'s per ton dry weight).

Graph 7.5. % Inclusion of wheat middlings at varying price against herring meal, meat and bone meal and soya bean meal at Jan. 1981 prices.

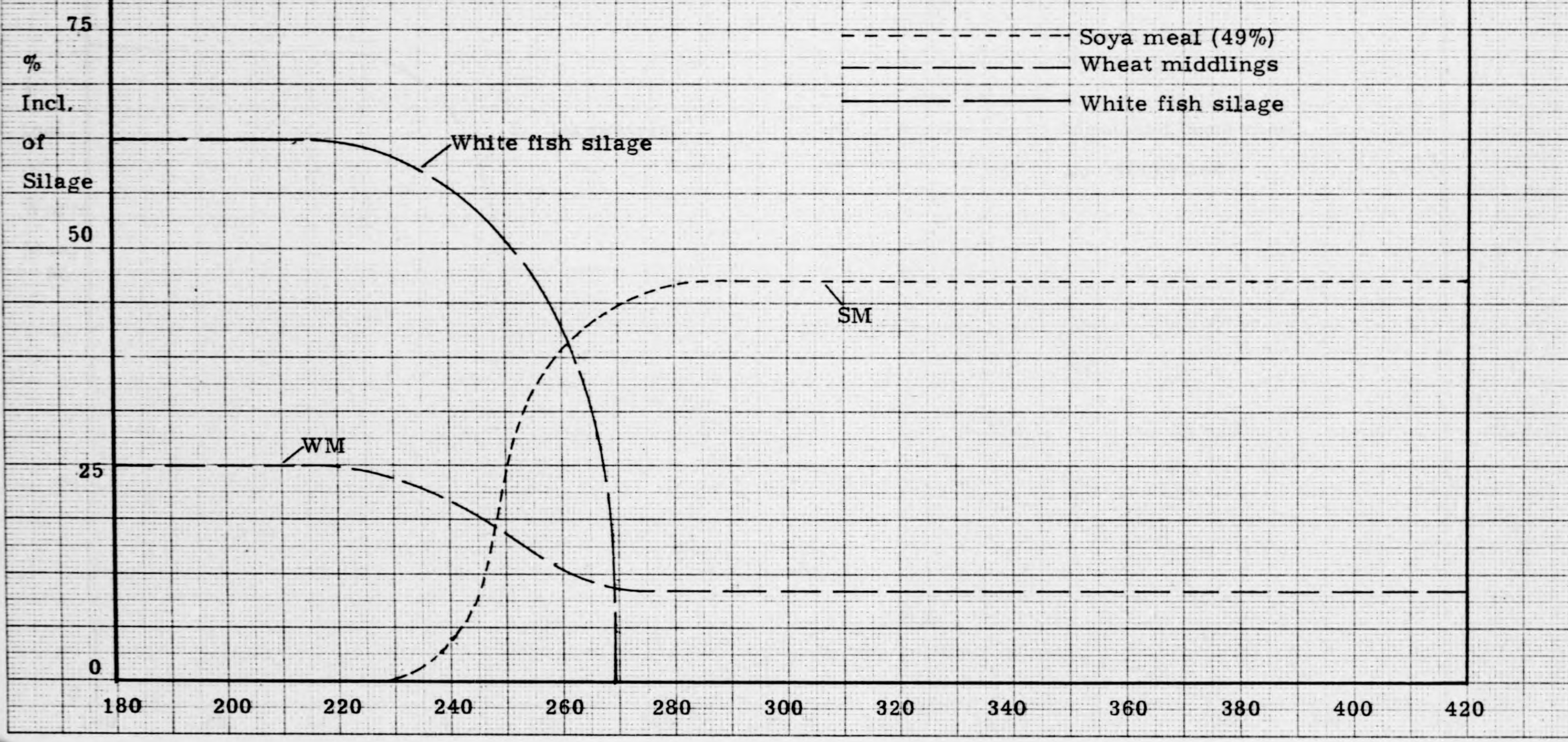


Price of wheat middlings (£'s per ton dry weight).

Graph 7.6. % Inclusion of fresh blood (dry weight) at varying price against herring meal, dried whey, soya meal (49%) and wheat middlings at Jan. 1981 prices.

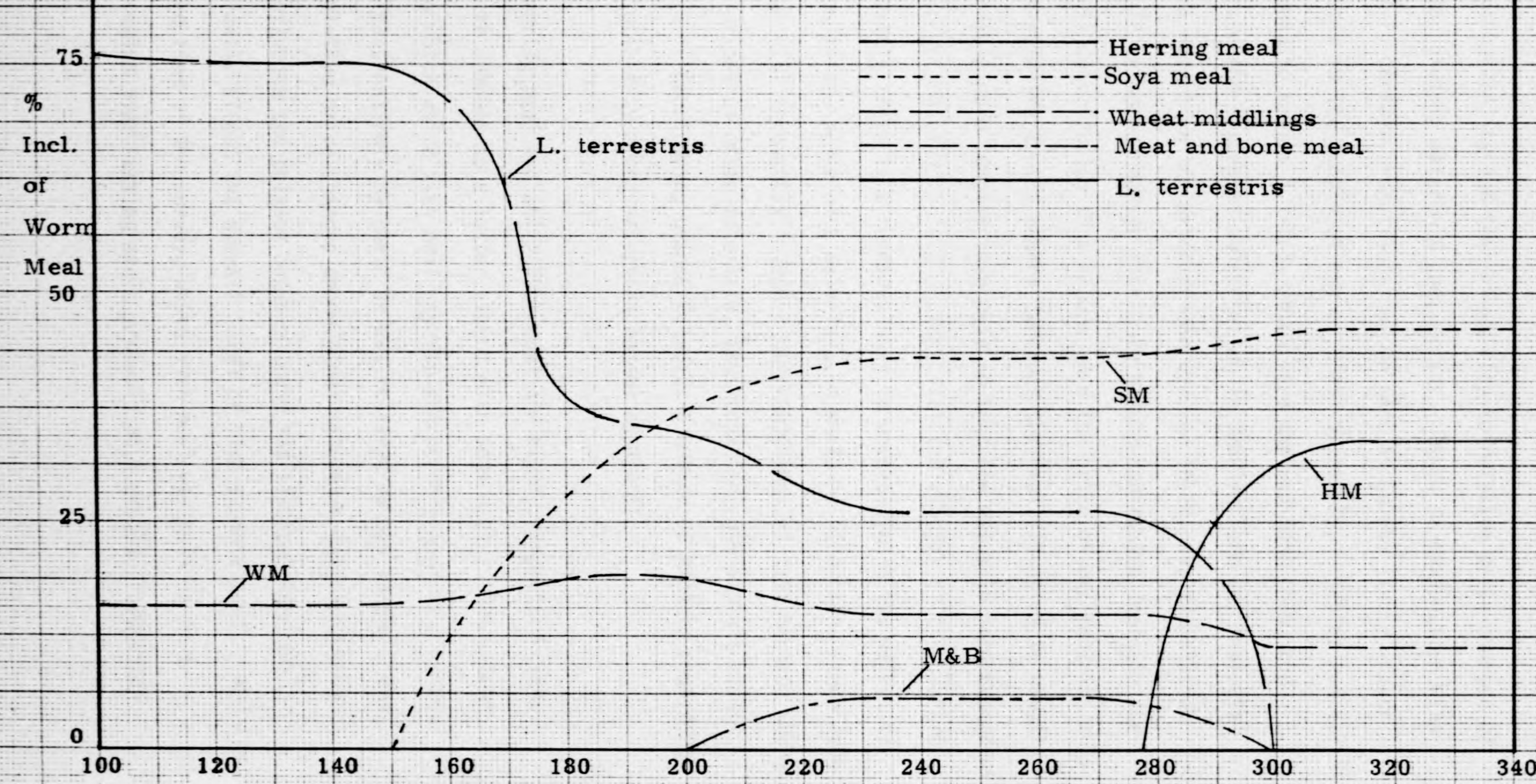


Graph 7.7. % Inclusion of white fish silage (dry weight) at varying price against herring meal, soya meal and wheat middlings at Jan. 1981 prices.



Price of white fish silage (£'s per ton dry weight).

Graph 7.8. % Inclusion of Lumbricus terrestris (dry weight) at varying price against herring meal, meat and bone meal, soya meal (49%) and wheat middlings at Jan. 1981 prices.



Price of L. terrestris (£ per ton dry weight).

of substitutability and the sensitivity to relative price changes of the major protein materials considered. Taken in conjunction with table 7.1, certain projections may be made as to the likely impact of changes in the supply of any of these materials. Tables 6.4-6.7 correspond to graphs 7.1-7.8, which were derived from them, and illustrate the degree of substitution in tabular form and indicate also the effect on the price of the derived least cost formulation. It should be noted however that both graphs and tables indicate the manner of substitution that occurs when the price of one material only changes relative to the others, whereas the real situation is usually considerably more complex than this in that the mutually interdependent price structure tends to act against isolated changes of this nature. Consequently there is a tendency here to underestimate the effect of a change in the price of a material, in whatever direction, since such a change will frequently induce a corresponding, if less marked, change in the prices of other materials, thus enhancing the overall effect.

Considering graphs 7.1-7.8, a number of factors regarding substitutability among materials become apparent:

- Herring meal and white fish meal are highly competitive, and both compete to a lesser extent with soya meal. The extent to which white fish meal may replace herring meal is governed almost entirely by their prices relative to one another, and relative price changes among other materials do not greatly influence the balance between these two although they may greatly affect the overall level of fish protein used. At the time of the survey, white fish meal was selling at a premium over herring meal, probably as a result of reported adverse effects of high levels of herring meal in some stock feeds.

- Soya meal and meat and bone meal both compete fairly strongly with wheat middlings but not apparently with one another. None of these materials, along with dried whey, are suitable for very high levels of inclusion in trout diets on account of the need for a high overall nutritional content of the feed, and their level of inclusion does not rise greatly even at very low prices since their prime function is to replace the more expense proteins to a level that remains nutritionally acceptable. Soya meal, on account of its higher protein quality, may however constitute slightly over 50% of a diet under current (Jan. 1981) economic circumstances, sparing more expensive materials.
- A number of common agricultural feedstuff ingredients are normally priced too highly to recommend their inclusion in cost effective trout diets. This emphasises the essentially insignificant role of the trout feed industry in determining ingredient prices which are influenced far more by the overall supply and demand in the traditional agricultural feed markets associated primarily with conventional stock.
- Blood appears to compete more strongly with the vegetable proteins than with herring meal, against which it exhibits only a slight sparing action. This must depend very much however on the unknown factor of the digestibility of fresh blood in trout diets. Certain of the cultured foods studied, of which L. terrestris is taken as the prime example, could compete effectively with the high protein animal materials already in use. Many of the other

cultured foods however are of lower nutritional value and would compete more effectively with soya meal and could only be included at reduced levels in conjunction with other high protein materials.

In general, linkage between prices of materials increases with the degree of substitutability. This is modified however by the nature of the producer industry, and competition among producers of one item may prevent a full response to relative price changes in other items, while items produced at low profit margins may also be unable to respond to reduced prices of competing items. Whenever the price of an item fails to respond fully to relative changes in competing products, this is adjusted instead in revised levels of output and demand (represented in graphs 7.1-7.8 by the levels of inclusion in the optimised diets).

Section 2 of table 7.1 covers single cell proteins, distillers' residues also being included on account of their production association with yeasts.

"Pruteen" bacterial protein, yeasts and dried distillers' residues have a recognised place in agricultural feedstuffs. Yeasts are likely to continue to be used in compound trout diets on account of their vitamin content and apparent beneficial effect, but are too highly priced to be used as other than a minor constituent. "Pruteen" and distillers' dried residues are both intended as major dietary components, although the nutritional quality of the former is clearly much greater. Distillers' residues have found extensive use in cattle feeds, where their sparing action on more expensive materials has set a price close to or in excess of their value to the trout farmer. This latter is reduced owing to the nutritional inadequacy of this material in diets for the more demanding trout necessitating extensive compensation with higher quality protein materials. While it can be and sometimes is successfully used in trout feeds, therefore, it is likely that its use in this manner will remain marginal so long as a more suitable market exists in conventional stock feedstuffs.

"Pruteen" is a very much higher grade material but nonetheless its specific amino acid profile restricts its value to the trout farmer while justifying a comparable price to fish meal when used in compensating lower grade materials in the formulation of conventional agricultural feeds, especially those directed at the quality end of the market associated with young stock, for which purpose it is nutritionally more appropriate. A relatively minor price shift in this material could however bring it within the range tolerated by the slightly different requirements of the trout feed industry.. If this should occur, the potentially large quantities available could promote this material as a major stabilising factor in the price of trout feeds.

A.S.C.P. does not appear to have a major role in trout or other animal feedstuffs at the present time due to the high cost of processing, and the future usefulness of this material will depend essentially on technological advances in dewatering methods or on the dewatering being undertaken at someone else's expense for other motives, e.g. to facilitate disposal. Assuming the fulfilment of either of these two conditions, the relatively poor protein quality would tend to favour its use in agricultural rather than in trout feeds and would set a price commensurate with its use in the former, its value in the latter being reduced by the need for compensation by more highly priced materials. Similar economic considerations apply to the use of aquatic weeds, although both these and A.S.C.P. could possibly find a valuable role in the culture of vegetarian and/or planktonic fish species at the site of production thus eliminating the need for expensive processing techniques.

Substitutability of these materials was not investigated as fully as for those in section 1. "Pruteen" would be expected to compete most strongly with the animal based meals and soya meal, being intermediate in protein quality. Distillers' residues would be expected to compete most strongly with wheat middlings and to a lesser extent with soya meal and meat and bone meal, while A.S.C.P. would probably compete with meat and bone meal.

Section 3 covers potentially cultured food items, and entries in column 5 indicating estimated cost per ton must therefore be considered as very much more tentative than for sections 1 and 2 of the table.

Clearly the great majority of the cultured items investigated show little immediate promise of economic viability, due largely to a combination of high material costs and poor conversion efficiencies or to the high costs of extracting, handling and processing the product. These factors are discussed more fully in the relevant sections of the text.

The only major exception to the above concerns the culture of earthworms of various species on a medium of animal manures. If available at the estimated price (the cost of production remains largely untested) earthworms could complete very effectively with herring meal, and meal at £290 per ton (Jan 1981) would be virtually interchangeable with herring meal at £300 per ton, with slight balancing adjustments in the level of soya meal and wheat middlings (graph 7.8).

At the lower price of £170 per ton, earthworm meal also competes effectively with soya meal. This corresponds to a wet weight of £46 per ton, only marginally below the rather uncertain estimated cost of production. Nonetheless it should be realised that the large scale culture of worms would depend on a constant supply of animal manures, most readily available from intensive livestock units with their own requirements for feed materials. This situation might well result in the producers of the manure gaining overall control of the proposed culture of worms such that in a relatively short time little of this material would become available to the trout farmer at a price lower than the opportunity cost to the intensive unit supplying the raw material.

In all cases, it should be noted that the values given vary depending on the circumstances of use, and in particular those items evaluated by least cost analysis of a moist diet formulation based on 9 variable nutrient sources as in table 6.4 may differ slightly from values given for the same items in appendix H based on up to 20 variable nutrient sources as in appendix C. This relates back to chapter 1 where it is suggested that increasing the number of materials available to the compounder can result in reduced dependency on a particular item, and hence the reduced value of the item as well as the reduced overall cost of the diet.

While the range of materials able on a nutritional basis to effectively substitute for the cheaper vegetable proteins in trout feeds is extensive, their value in this manner is lower than the opportunity cost relating to their use in conventional agricultural feeds. The opportunity cost of the high grade materials (e.g. fish meal) tends to be lower than their value to the trout feed compounder since conventional agricultural feeds may substitute with cheaper materials to a greater extent than is nutritionally acceptable in trout feeds. Thus krill, earthworms and bacterial protein are the most significant novel materials with regard to the trout culture industry. Only the last of these is currently in large scale commercial production, although the other two offer possibilities for the future.

A number of wet materials - industrial fish and fish offals, shellfish offals, meat offals and blood - may in favourable circumstances be used to replace the highly priced animal based proteins generally supplied in compound pellets, but the higher costs involved in particular with storage and transport dictate that the source of supply should be regular and local as well as being cheap. These circumstances may prevail in some areas such as near year round fishing ports and isolated slaughterhouses, but are unlikely to make much impact on the trout culture industry as a whole.

7.3.2 Developments of new feed types: The second major aspect of reducing feed costs in trout farming concerns the prospect of alternatives to the use of commercially prepared compound feeds, such as wet feeds, moist compound feeds, and farm prepared dry compound pellets.

The use of wet feeds assumes the use also of alternative feed ingredients as opposed to the meals used in conventional compound feeds and has already been considered in this context, while the farm based preparation of dry compound pellets was regarded as impractical feeds. The opportunity cost of the high grade materials (e.g. fish meal) tends to be lower than their value to the trout feed compounder since conventional agricultural feeds may substitute with cheaper materials to a greater extent than is nutritionally acceptable in trout feeds. Thus krill, earthworms and bacterial protein are the most significant novel materials with regard to the trout culture industry. Only the last of these is currently in large scale commercial production, although the other two offer possibilities for the future.

A number of wet materials - industrial fish and fish offals, shellfish offals, meat offals and blood - may in favourable circumstances be used to replace the highly priced animal based proteins generally supplied in compound pellets, but the higher costs involved in particular with storage and transport dictate that the source of supply should be regular and local as well as being cheap. These circumstances may prevail in some areas such as near year round fishing ports and isolated slaughterhouses, but are unlikely to make much impact on the trout culture industry as a whole.

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The use of wet feeds assumes the use also of alternative feed ingredients as opposed to the meals used in conventional compound feeds and has already been considered in this context, while the farm based preparation of dry compound pellets was regarded as impractical for the following reasons:

- Competition between compounders reduced the level of profit margins and thus restricts the possibility of a venture on an individual farm basis, although it is acknowledged that a cooperative venture by a number of farms could overcome any diseconomies of scale pertaining to a single farm.
- Capital expenditure involved in the plant and equipment required for dry pellet production is considerable.
- It would add to the cost of preparation of a diet which could in most cases be used without such elaborate processing.

Accordingly the main avenue explored in this context was the on-site preparation of moist compound pellets, formulated from both standard and novel materials.

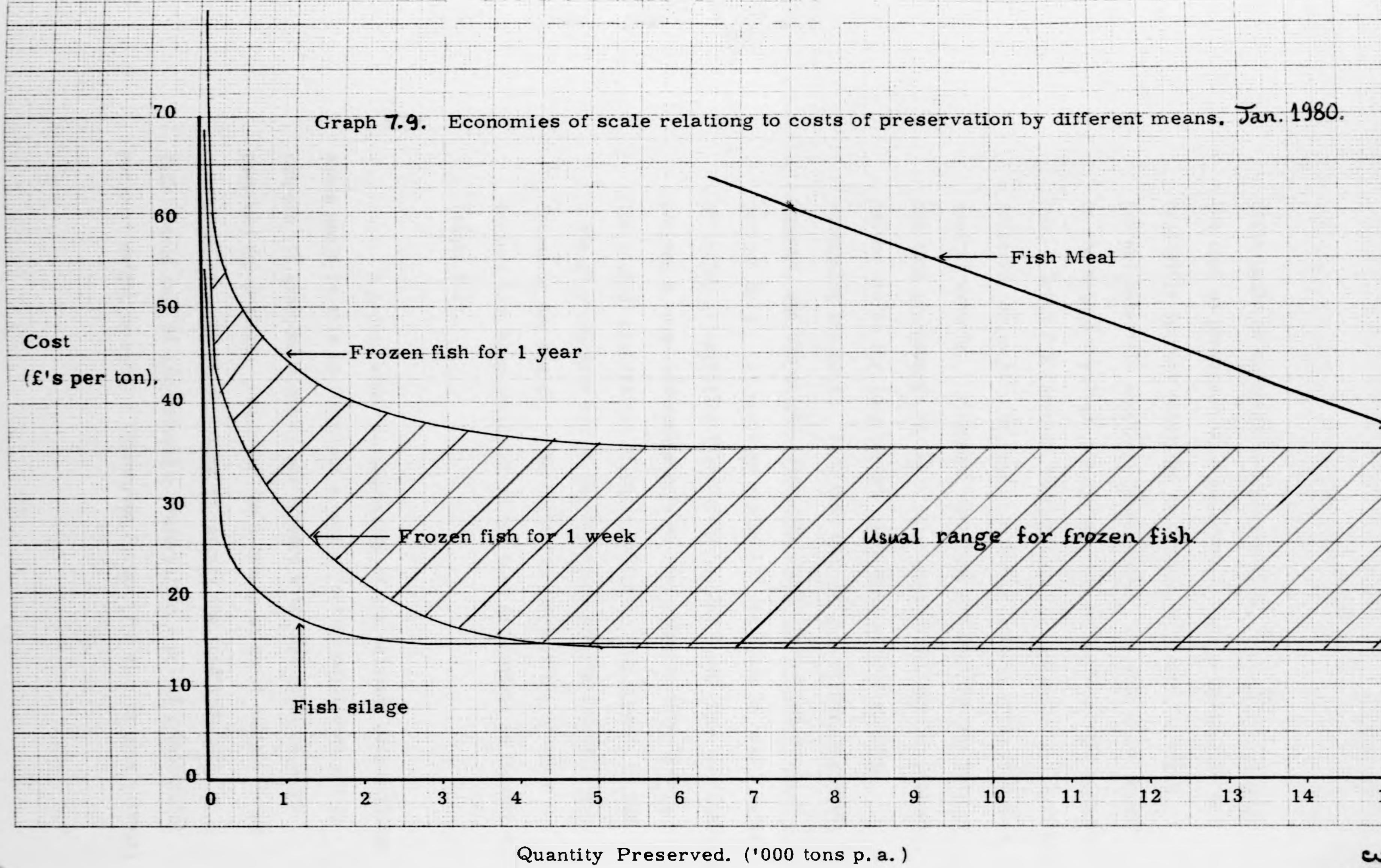
A number of simple moist dietary formulations are costed in table 6.3 on the basis of their ingredients (prices as at Jan 1981). By applying linear programming least cost techniques it is possible to optimise these and similar moist diets, and this was done on the basis of 10 readily available dietary ingredients subject to the same constraints as are detailed in chapter 2, but with revised levels of dried brewers' yeasts, cod liver oil and vitamin/binder (2%, 2% and 4% respectively) to allow for the fact that these formulations refer to moist pellets for which the addition of a binder is considered desirable. The optimised formulation at Jan 1981 prices is shown in table 6.4, along with indications of the manner in which the formulation would change in accord with relative price changes among the ingredients (from which graphs 7.1-7.5 are derived, as discussed in section 7.3.1).

Needham (1981) states that a simple tabulation of typical practical feed formulations for trout or salmon would be of considerable benefit to the industry and would permit fish farmers to prepare their own rations as is the case in so many other branches of UK agriculture. Tables 6.1, 6.3 and 6.4-6.7 provide a number of such formulations, but it must be recognised that the diets thus represented are either not optimised or are optimised only for the ingredients listed and at the relative prices indicated. It is of course possible for a farmer provided with a number of such formulations to cost each of the diets according to the prevailing prices of ingredients and then to select the cheapest, but such a method would be tedious and would still under most circumstances produce a less than optimal formulation. A better solution would be for each individual farmer to have a linear programming model based on the ingredients available to him which could be run as required whenever ingredient prices changed. Note however that the cost of the diet is fairly stable around the least cost optimum and does not change rapidly in relation to price changes among the main ingredients. Frequent optimisation runs to allow for minor changes in ingredient prices may therefore not prove cost effective.

In order to compare the merits of a moist diet against a dry compound pellet, as opposed to other moist formulations, however, the following other factors would require to be known:

- The conversion factor, diet/trout: For all diets formulated according to the constraints specified, this would be expected to resemble or better that achieved using standard compound pellets on a dry weight to weight of trout basis (generally around 1.8/1). Thus the conversion ratio for these moist

Graph 7.9. Economies of scale relationg to costs of preservation by different means. Jan. 1980.



diets would be expected to approximate to $\frac{1.8 \times 100}{\%\ \text{dry matter in diet}}$ 1.

- The cost of preservation of materials: This is assumed to be negligible for dry materials or for wet materials fed fresh. For wet materials requiring preservation, the cost would depend on the method involved, the period, the material and the throughput. Graph 7.9 (derived from section 3.1) attempts to illustrate preservation costs with regard to these factors, using fish as a typical example. With meal reduction and ensilage the bulk of the cost is incurred in the initial processing, and the products may be stored for long periods afterwards without greatly increasing the cost. This does not apply to frozen materials, however, and the graphs illustrate costs for two preservation periods only. It would be preferable therefore to have a series of graphs illustrating freezing costs, and those shown can therefore provide a rough indication only on the extent of this factor.
- The cost of preparation of moist pellets: This depends on the scale of production and on the manner of materials used (fresh, frozen or dry meals). The costs for combinations of these factors have been presented in the form of a matrix in chapter 6 (table 6.2).

A trout farmer in possession of the relevant data outlined above would be able to formulate a cost effective moist diet and to compare its expected economic performance with that obtained using compound dry pellets. In order for a change to moist pellets to be justified, it would be necessary to satisfy the condition that:
((Delivered cost of ingredients + preservation + pellet preparation) per unit weight as used) X Conversion factor (for diet as used : trout)

<(Delivered cost of commercially prepared dry pellets per unit weight as used) X Conversion factor (for diet as used : trout).

The right hand side of this equation must be calculated from previous records. To insert values on the left hand side it is necessary for the farmer to obtain estimates for delivered prices of available ingredients on which a linear programming analysis would be run to optimise and calculate the price. To this figure would be added an estimated cost of preservation and an estimated cost of preparation and handling of the moist pellets based on the most appropriate example among those listed in table 6.2. The expected conversion factor would be estimated from the water content as described previously (subject to the formulated diet meeting the constraints imposed).

This relatively simple procedure would enable the fish farmer to judge whether a change to a farm-prepared moist diet would be likely to yield economic advantages over a dry compound pellet. It could not of course substitute for practical field trials but would be intended as a guideline to further action only.

It is unfortunately not possible to provide a model that is both accurate and general in its application due to the unique circumstances relating to each culture system which preclude the provision of specific costs relating to such factors as storage and delivery, and accordingly any initial economic benefits indicated would need to be confirmed by a fuller analysis based upon estimates obtained for a specific set of proposals.

A least cost analysis of the diet is central to the optimal use of farm-prepared compounds, but would need to be run regularly in order to remain relevant. This might prove troublesome and expensive for some of the smaller units, such that there is a strong argument in favour of the cooperative employment of such a program, especially for farms in close proximity having similar access to ingredients. The operation of a comprehensive linear programming package on a regular basis might be particularly well suited to a subsidised government body or a fish farming journal where results of the analysis could be published regularly as a service to the farmer. Alternatively the farmer could make use of a consultancy body to optimise the diet at intervals as required on the basis of the farmer's own nutritional data. Either option would result in more efficient use of the material resources available.

7.4 CURRENT PROSPECTS AND PROPOSALS FOR THE REDUCTION OF COSTS IN TROUT FEEDING

On the basis of what has been written, the potential usefulness of those items originally selected for study in Section 2.2 is summarised in the form of a matrix (Table 7.2). The first section deals with those materials which could potentially replace standard ingredients in commercially manufactured dry compound pellets. As such they are of less immediate interest to the trout culturist since the factors which affect their use are outside his immediate control. They could well be of importance however in the longer term structure of the industry, depending largely on the behaviour and trends of those other standard ingredients with which they might compete, as discussed in Section 7.5

There is at present a substantial body of evidence to suggest that the majority of UK trout farms could benefit economically for some of the smaller units, such that there is a strong argument in favour of the cooperative employment of such a program, especially for farms in close proximity having similar access to ingredients. The operation of a comprehensive linear programming package on a regular basis might be particularly well suited to a subsidised government body or a fish farming journal where results of the analysis could be published regularly as a service to the farmer. Alternatively the farmer could make use of a consultancy body to optimise the diet at intervals as required on the basis of the farmer's own nutritional data. Either option would result in more efficient use of the material resources available.

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There is at present a substantial body of evidence to suggest that the majority of UK trout farms could benefit economically

7.2 PROSPECTS FOR REDUCTION OF FEED COSTS

	V.Slight or none	Slight	Fair	Good
Replacement protein materials for inclusion in commercially manufactured compound pellets.	Distillers' dried resd. - already used as replacement for veg. materials but with no real impact on price. A.S.C.P. - high processing costs.	S.C.P. - may serve to underpin prices and reduce dependence on fish meal.	Worm meal - potentially available at similar price and quality to fish meal.	Krill meal - potentially available at lower price than fish meal should human market develop for tail meats.
Ingredients in farm prepared moist compound pellets.	M. domestica - too highly priced. Aquatic detritivores - better used in situ for extensive culture Seal meat - high cost and restricted availability	Meat offals - may be useful in certain local situations only. Mussels - high price restricts potential, but have been used successfully in moist diets for other species.	Fish and fish offal - available in many areas at regular prices. Blood - very useful if obtained cheap locally but may only be used in small quantities in compound diets due to its liquid nature.	Worms - stable supply possible at competitive estimated costs. Cheap storage if cultured to sites with access to large quantities of manure.

from a switch to the on-site preparation of moist pellets, although it is probable that such an action would increase the pollution load of the effluent and might not therefore be permitted, depending on the circumstances of the farm and the attitude of the relevant water authority. In its simplest form, moist pellet preparation would entail the mixing of meals in fixed amounts with water and extrusion via a pelleting machine shortly prior to feeding. It is estimated that this could reduce feeding costs by up to 50% under ideal circumstances (Table 6.3), although it must be appreciated that not all farms will have access to the dry meals envisaged at ex works prices, and costs would require to be adjusted according to delivery charges from the nearest supply point. At this level of return, the payback period for the capital expenditure on mixing, pelleting and accessory machinery (estimated at apprximately £6000 for a unit producing 150 tons of trout in 1981) could amount to less than six months.

This simple approach of preparing moist feeds from dry meal ingredients might well prove the best solution for the majority of farms, although it could generally be further improved by regular re-optimisation of the diet with respect to price and by the adoption of a cooperative approach to formulation and preparation where a number of farms are associated geographically. The particular attraction of moist diets for many farmers however is that it would permit the efficient exploitation of cheap ingredients available locally and could also in some circumstances permit the culture of protein ingredients. Fish and fish offals, blood and meat offals could all be used economically as a replacement for the higher protein meals in the formulation of moist diets in a number of localities, and would furthermore permit the return to dry meals in times of scarcity of the fresh material with a minimum of effect on the final composition of the diet, thus avoiding the need for relatively heavy investment in freezing and grinding machinery. Where fresh raw materials ave available throughout the year however then freezing equipment would almost certainly be desirable to even out short term fluctuations and to permit some degree of flexibility in optimising delivery sizes and frequencies. The long term storage of materials available on an intermittent basis only (e.g. the seasonal operation of a fishery or slaughterhouse) would not appear to be feasible and where such situations arise the optimum solution would be to use a moist diet prepared from dry meals throughout the year and to replace the meal component with its fresh equivalent only as and when this was available at a lower relative cost.

As regards specific materials which might be used to replace dry meals in a moist diet, worms (L. terrestris and L. rubellus) would appear to offer excellent prospects of ensuring a competitively priced product of high nutritional quality throughout the year and in whatever quantities were required, subject to access to sufficient quantities of animal manure, e.g. from an intensive livestock unit. Feasibility of production on the scale envisaged has yet to be demonstrated in practice, however, and the relevance of continuing work being conducted at Rothampstead experimental station and by Dr. Albert Tacon at Stirling University is noted.

Of the materials already available, fish and fish offals appear to offer immediate benefits to many farms close to a source of supply when used in conjunction with on-site preparation of moist pellets. Although fresh fish has been used on occasion and has since been discontinued, its use in combination with cheaper, lower grade materials greatly increases its economic efficiency and, as virtually isoproteinaceous with fish meal plus added water, could be interchanged at will with the latter whenever supplies of the fresh material rose in price or became in short supply. Fish silage could be similarly used, and is relatively cheap both to prepare and to store and might therefore prove more attractive than the use of fish meal in areas where periodic gluts occur in fish landings.

Blood is expected to become a useful ingredient in trout diets if it can be obtained at a price of £17 per ton or less (1981 prices), although its composition and quality and hence its value in trout feeds is believed to vary to a considerable extent between sources of supply and analysis should be obtained prior to formulation of the diet. The degree to which blood could be incorporated in a moist diet is of course limited by its liquid nature. Nonetheless from a survey of Scottish abattoirs it appears that there are numerous sources of this material within the price range quoted, and blood could well provide significant financial benefits to a number of Scottish trout farms if moist pellets were adopted. Meat and meat offals are similarly widely available and prove suitable for inclusion in moist diets at fairly high levels, but are not generally obtainable at prices of much less than £100 per ton such that their use in this fashion remains economically marginal.

Other materials studied are considered unsuitable for widespread inclusion in moist trout diets, generally on account of their high cost of purchase or production. There are of course large numbers of other potential feed materials that have not been considered in this thesis on account of a restricted availability that may nonetheless prove useful on a windfall basis to those farmers in a position to exploit them, while the usefulness of all of these materials is subject to a certain amount of temporal variation, as considered further in Section 7.5, and recommends occasional reformulation and reappraisal of diets if economic efficiency is to be maintained.

7.5 TRENDS AND FUTURE DEVELOPMENTS IN COMPOUND FEED PRICES

Feed prices do not vary regularly with respect either to time or to one another, and Graph 7.10 illustrates trends for general agricultural feeds, trout feeds and white fish meal between 1976 and 1981.

The price of fish meal has recently been rising rather faster than the price of compound feedstuffs due to depletion of stocks and escalating costs in the fishing industry worldwide. General feed compounders are less critically affected by this due to the minority role of these ingredients, and can offset such rises to some extent by progressive substitution of price volatile material whenever this becomes economically expedient. Compound trout feeds are more tied, being far more dependent on these high quality animal based proteins. While the outlook on fishmeal prices is highly uncertain, and depends in part on the success or otherwise of the current negotiations concerning fishing quotas and conservation efforts, it is probable that the price of these materials will continue to outstrip those of the plant based proteins on account of the increasing marginal cost of fishing viewed over the longer term. The effect of increasing fish meal prices has been counteracted to some extent by the recent rapid advances in our knowledge of trout nutrition, enabling increasingly cost effective diets to be formulated, and further developments in this field are now likely to suffer from diminishing returns as fewer avenues exploit them, while the usefulness of all of these materials is subject to a certain amount of temporal variation, as considered further in Section 7.5, and recommends occasional reformulation and reappraisal of diets if economic efficiency is to be maintained.

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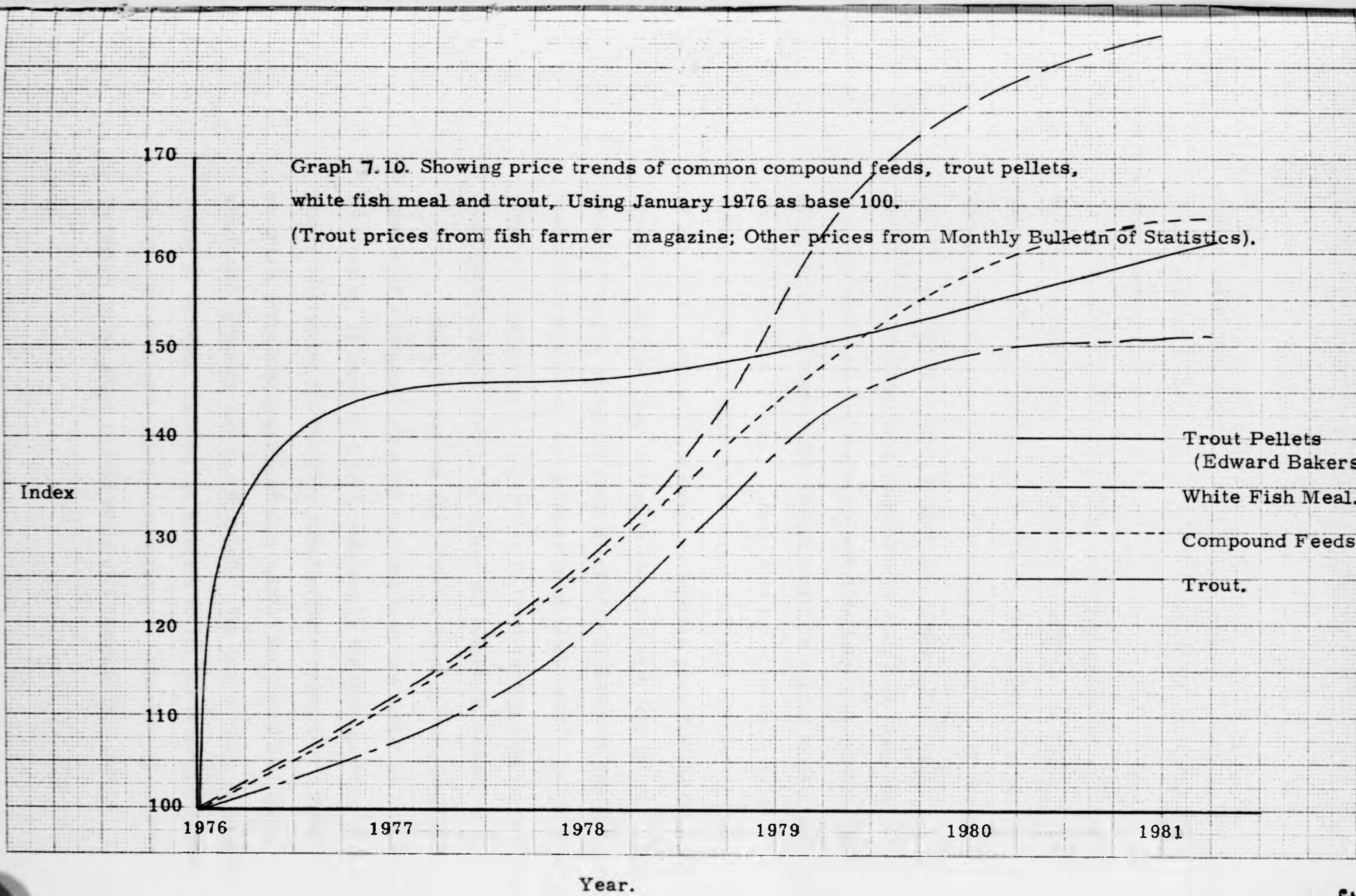

Graph 7.10. Showing price trends of common compound feeds, trout pellets, white fish meal and trout, Using January 1976 as base 100.
(Trout prices from fish farmer magazine; Other prices from Monthly Bulletin of Statistics).

remain unexplored, and the net effect is considered likely to be a higher rate of price inflation for trout feeds than for other compound feeds.

The price of trout over this same period has been falling relative to feed prices. A resulting squeeze on profit margins may check or reverse the recent growth in the UK culture industry, probably by the forced closure of the less economically efficient units. To date the market in trout has tended towards price inelasticity of demand when compared with other fish products, probably due in part to the major outlet in catering establishments where the actual cost of the item is masked to a great extent by the ancillary catering charges. Should this price inelasticity be sustained, then any reduction in output resulting from the closure of uneconomic units will encourage an improved price for the remaining production enabling trout prices to keep pace with feed prices. Any tendency towards increasing price elasticity of demand on the other hand would reflect the increasing price of feeds relative to price of trout in a continuing decline in the UK trout farming industry and would greatly hamper efforts to expand the home-sales market.

While the outlook for intensive trout culture based on commercially prepared compounds does not therefore appear particularly encouraging, it could be greatly enhanced by the development of price-stable substitutes for the high animal protein components. Three materials offer some promise of this - krill meal, worm meal and single cell proteins such as "Pruteen". The last of these is on the limits of economic viability with regard to its use in the trout feed market under present economic circumstances. However, any further increases in the price of fish meals will increase the value of petro-protein as a potential replacement in trout diets, and while it may not therefore be of immediate benefit to trout farmers its proximity to economic viability in this respect could serve to restrain further price rises in compound trout feeds as a whole and to thus introduce a strong stabilising influence into the market.

The future use of krill meal is much more speculative, but could be of much greater benefit to the trout farming industry on account of its high protein quality. While it may prove an acceptable substitute for fishmeal in the longer term, however, the availability of krill meal must depend on the development of a human market for the tail meats to stimulate the expansion of the krill fishing industry.

The use of worm meal is similarly speculative with regard to its production costs, although its nutritional properties are comparatively well known.

Clearly the major problem pertaining to trout feed formulation is that the carnivorous nature of the trout necessitates the use of the highest quality proteins, and yet is not in itself a sufficiently large market to influence the price of these materials which are governed instead by supply and demand within the very much larger agricultural feed market. The long term solution for the trout culturist must therefore lie in large measure with the development of a high quality digestible protein whose price is not subject to the same pressures as fishmeal, or alternatively in reducing the dependence of trout on high quality proteins, e.g. by the supplementation of cheaper materials with synthetic amino acids where the price of the latter is sufficiently low to justify their use.

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CHAPTER 8

Conclusions

8.1 CONCLUSION

The prime objective of this thesis as outlined in the preface was to explore means by which feed costs incurred in trout culture may be reduced or stabilised. Methods of achieving this have been divided into two categories relating to the production, development and evaluation of novel feed materials or of conventional feeds not currently used in UK trout culture, and to the development of more economical means of utilising existing materials. In general terms chapters 3, 4 and 5 consider the former of these two aspects and chapter 6 the latter, although there is necessarily a great deal of overlap between the two approaches. Chapters 1 and 2 serve as an introduction to the topic of trout culture in general and to the economics of trout feeding in particular, and chapter 7 summarises the major findings of the thesis in the overall economic context.

The wide ranging nature of the study and the intended amalgamation of biological and economic disciplines precluded specific experimental investigations into any one aspect and it has proved necessary to draw heavily upon the published work of others to provide much of the raw data required. Practical work was limited to the feeding trials used as part of an initial screening device for candidate materials and to a number of analyses for nutrient composition and amino acid profiles where these were missing from the literature, while much of the data referring to practical aspects of the study, e.g. costing of materials and processing machinery, etc, was obtained from manufacturers lists or by personal communication with industries and concerns appropriate to the process under investigation. This methodology clearly differs substantially from the more straightforward approach that can be adopted in most scientific disciplines where experimental exercises can be designed at the initial planning stage to provide the required data relating to specific aspects of the overall thesis plan.

A major problem was encountered in attempting to compare costs and in the reduction of costs and prices to a common basis for purposes of corporate calculations. Where possible costs relating to a single process were obtained for a common date, but where this proved impossible costs were adjusted according to appropriate indices such as those contained in the Department of Industry's monthly issue of price index numbers (costs thus adjusted have been indicated in the text). The majority of costs quoted have been obtained for or adjusted to January 1980 prices, although the costs of moist pellet formulations in chapter 6, being researched at a later date, have been adjusted where necessary to January 1981 prices instead as it seemed undesirable to use outdated costs when more recent information was available.

The major findings of the thesis have emerged in chapter 7. The price fluctuations of traditional compound trout feeds reflect that of agricultural commodities, notably fishmeal. Over the longer term this key raw material is subject to the increasing marginal cost of its producer fishing industry. Potential substitutes for the major meal materials used in the production of dry compound pellets are relatively few in number. The influx and increased availability in recent decades of foreign imported high protein vegetable materials has proved to be of lesser benefit to trout culture than to other branches of agriculture on account of the high quality protein requirements of the trout, and animal based proteins, of which comparatively few remain unexploited, are likely to produce a greater impact.

Krill meal, worm meal and industrial micro-proteins appear as potential substitutes for the highly priced animal proteins on which the industry is currently so heavily dependent should favourable economic conditions arise, but none of these are yet commercially available at a price which would allow their immediate use in trout diets. Continuing progress is expected in the development of an industrial krill fishery and in the culture of worms as a feedstuff. A.S.C.P., on the other hand, is not regarded as potentially useful in the provision of cheap trout feeds, at least in the medium term, on account of its high processing costs and low nutritional value.

Numerous other materials, including fish, shellfish and slaughterhouse offals, have proved useful in the past and could continue to be modestly successful in specific localities with favourable access to the raw materials, but would generally be more efficiently utilised when compounded into a farm-prepared moist pellet. There is furthermore considerable evidence to suggest that the preparation of moist pellets from conventional meal materials only could be of financial benefit to a large number of UK trout farms, thus emulating the position in general agricultural systems where such practice is common, especially if diet optimisation techniques are used to maximise economic efficiency. That the use of moist pellets offers the prospect of substantial reductions in feed costs to the trout farmer might be expected since it circumvents the compounder's charges and the much higher costs involved in dry pelleting, and frequently avoids also the meal reduction costs of some of the ingredients. Nonetheless it must be borne in mind that pollution may be increased by the use of wet or moist diets as opposed to dry pellets, and that this practice has been curtailed both in this country and abroad on these grounds in the recent past, such that circumstances relating to the farm's water supply would also require to be ascertained.

Needham (1981) states that there is a lack of information available on simple practical formulations for fish diets, and this factor and the increased pollution constraints imposed on a water-based culture system might partly explain the apparent lag of fish farming behind mainstream agriculture in this field. It is to be hoped that this thesis will go some way towards filling this gap. A certain amount of capital outlay and a previous lack of economic analysis detailing the benefits might further have curtailed the use of moist pellets, and a rapid expansion in this field is now plausible in areas where water pollution constraints are less severe, such as in coastal areas suitable for trout farming.

It is inevitable that much of the economic data presented in this thesis will become outdated. Nonetheless the biological data presented (conversion ratios, nutrient analyses, etc) and the methodology used in costing alternative diets should, bar minor modifications resulting from improved measurements, remain fairly constant such that it is hoped that this work may remain useful as a framework for feed evaluation despite relative changes in the prices of the materials examined.

8.2 SUMMARY

The major conclusions to be drawn from this work are as follows:

1) Trout feed costs are highly dependent on the high quality protein element, traditionally supplied by fishmeal. This material is in wide demand for use in conventional livestock feeds and fluctuates markedly with regard to availability and consequently price, thus influencing trout feeds also, but the long term trend of fishmeal prices is upwards in real terms due to the increasing marginal costs of fishing.

2) The increasing price of fishmeal is likely to further raise the price of potential substitutes, albeit to a lesser extent, whereas many of the potential substitutes for fishmeal in general livestock feeds are of reduced value in trout feeds due to the specific requirements of the trout for high quality protein.

3) Some opportunities do exist for farmers to obtain feed economies, particularly when they can exploit local materials for which opportunity costs are low. In such cases, the preparation of moist pellets would generally make the most efficient use of resources available, although the likelihood of increased effluent may restrict this practice depending on the farm's circumstances relating to water supply. There do not appear to be significant short term benefits arising from the use of raw wet materials.

4) Concerning the possibility of culturing feed organisms on organic wastes, only earthworms show reasonable prospects for success.

5) The most promising large scale downward constraints on trout feed prices are the possible realisation of supplies of krill meal and worm meal as being more stable substitutes for fish meal.

6) Further research in trout feed requirements will continue to help restrain trout feed prices as increasingly efficient diets are

prepared with the materials available, although such work will eventually suffer from diminishing returns.

8.3 RECOMMENDATIONS

A number of recommendations may be made as to the most likely direction of areas of fruitful further research:

1) There is great scope for further work on digestibility studies to investigate the digestibility of a wide range of materials under varied conditions of use. The digestibility of plant proteins used in conjunction with synthetic amino acids in particular might prove valuable.
2) The technological feasibility of the mass culture of earthworms requires further attention.
3) There is a requirement for a wide-ranging study of the problem of pollution in the fish farming industry, relating to variation of effluent loadings with feed type and culture system, means of reducing pollution levels, and variations in the constraints imposed on the fish farming industry according to locality.

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AND

APPENDICES

REFERENCES

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APPENDICES

APPENDIX A

SUMMARY OF MAJOR PELLETED FEEDSTUFFS (JAN 1980)

Brand	Grade	% Prot.	% Fat & Oil	% Carbohydrate	£'s Per Ton
OMEGA	Trout fry				
	- No's 1 & 2	54	10	17	425
	- No's 3 & 4	54	10	20.5	405
	Trout (Floating)				
	- No's 4	47	8	22.5	305
	- No's 5 & 6	41	6	29.0	259
	- No's 6 (Pigmented)	41	6	29.0	287
	- No's 6 (High pigmented)	41	6	29.0	329
	Trout Growers (Slow Sinking)				
	- No's 5 & 6	45	7	22.5	279
	- No's 6 (Pigmented)	45	7	22.5	307
	- No's 6 (High pigmented)	45	7	22.5	349
	Trout (High Density)				
	- No's 4	50	8	19.0	295
	- No's 5 & 6	47	8	19.5	271
	- No's 6 (Pigmented)	47	8	19.5	299
	- No's 6 (High pigmented)	47	8	19.5	341
	Trout Holding Pellet				
	- No's 6	35	5	35	230
	Brood Fish (Floating)				
	- No's 7	50	7	20	330
	Salmon Starter				
	- No's 0, 1, 2 & 3	54	17	7	455
	- No's 4	54	17	7	435

APPENDIX A

SUMMARY OF MAJOR PELLETED FEEDSTUFFS (JAN 1980) (CONT)

Brand	Grade	% Prot.	% Fat & Oil	% Carbohydrate	£'s Per Ton
OMEGA	Sea Salmon (High density)				
	- No's 5, 6 & 7 (pigmented)	46	14	18.5	414
	- No's 5, 6 & 7	46	14	18.5	339
	Eel Meal				
	- Elvers	50			420
	- Eels	45			350
MAIN-STREAM	Trout fry				
	- No's 00 & 01	54	10		480
	- No's 02 & 03	54	10		440
	Fingerling				
	- No's 1	50	8		360
	- No's 2	50	8		314
	Table Pelleted				
	- No's 3, 4 & 5	47	8		280
	- No's 4 (Pigmented)	47	8		312
	Standard pelleted				
	- No's 3, 4 & 5	40	8		258
	- No's 4 (Pigmented)	40	8		290
	Standard Expanded				
	- No's 4	40	8		284
	- No's 4 (Pigmented)	40	8		312
	Breeder Expanded	50	6.5		354
	Holding Pellet	30	5		212
	Salmon Fry				
	- No's 00 & 01	54	14		520

APPENDIX A

SUMMARY OF MAJOR PELLETED FEEDSTUFFS (JAN 1980) (CONT)

Brand	Grade	% Prot.	% Fat & Oil	% Carbohydrate	£'s per ton
MAIN-STREAM	Salmon Fry (cont)				
	- No's 02 & 03	54	14		490
	Salmon Fingerling				
	- No's 2	50	14		374
	Salmon Grower				
	- No's 3, 4 & 5	46	14		350
	- No's 4 (Pigmented)	46	14		416
EWOS	Trout Starter Extra				
	- No's 1 & 2	42	15	21	
	- No's 3	40	15	23.5	
	Trout Grower Extra				
	- No's 4, 5, 6 & 7	38	16	23.5	
	Trout Holding Feed				
	- No's 4, 5 & 6	35	7	34.5	
	Trout Broodstock Feed (Pigmented)				
	- No's 7	38	16	23.5	
	Trout Grower (Standard)				
	- No's 4, 5, 6 & 7	45	8	23.5	
	- No's 8	45	8	23.5	
	Salmon Feed Extra				
	- No's 1 & 2	50	17.5	12.0	
	- No's 3	47	17.5	15.0	
	- No's 4	47	17.5	15.0	
	Salmon Feed Standard				
	- No's 1 & 2	53	12.0	13.5	

APPENDIX A

SUMMARY OF MAJOR PELLETED FEEDSTUFFS (JAN 1980) (CONT)

Brand	Grade	% Prot.	% Fat & Oil	% Carbohydrate	£'s Per Ton
EWOS	Salmon Feed Standard (cont)				
	- No's 3	50	12.0	16.5	
	- No's 4	50	12.0	16.5	
	Salmon Sea Food				
	- No's 5 & 6	45	15.5	19.5	
	- No's 5, 6 & 7 (Pigmented)	45	15.5	19.5	
	- No's 7A & 8 (Pigmented)	45	15.5	19.5	
SILVER CUP	Salmon and Trout Fry				
	- Starter	52			441
	- No's 1	52			441
	- No's 2	52			407
	- No's 3 (Crumbs)	52			370
	- No's 4 (Pellets)	50			322
	- No's 4 (Crumbs)	50			317
	Growers				
	- No's 5	45			261
	- No's 6	45			261
	- No's 6 (Pigmented)	45			285
	- No's 7	45			261
	- No's 7 (Pigmented)	45			285
	- Brood Stock (Pigmented)	50			322
TESS	Salmon Starter Feed				
	- No's 0, 1 & 2	51	20	10	497
	Salmon Grower				
	- No's 3 & 4	48	20	14	433

APPENDIX A

SUMMARY OF MAJOR PELLETED FEEDSTUFFS (JAN 1980) (CONT)

Brand	Grade	% Prot.	% Fat & Oil	% Carbohydrate	£'s Per Ton
TESS	Salmon Grower (cont)				
	- No's 4a	41	20	22	353
	Salmon Slaughter Feed				
	- No's 5, 6, 7 & 8	41	20	22	347
	- No's 5, 6, 7 & 8 (Pigmented)	41	20	22	378
	Trout Starter Feed				
	- No's 0, 1 & 2				497
	Trout Growth Feed				
	- No's 3 & 4				433
	- No's 4a				353
	Trout Slaughter Feed				
	- No's 5, 6, 7 & 8				297
	- No's 5, 6, 7 & 8 (Pigmented)				337
	Tess Meal Feeds				
	- Tess M. F. + Vitamins 10%				362
	- Tess M. F. + Vit. 10% + Pigm.				357
FULMAR	Trout Fry				
	- No's 1 & 2	53	12		570
	Fingerling				
	- No's 3	50	12		375
	Trout Grower				
	- No's 4	47	12		330
	- No's 5, 6, 7 & 8	47	12		300
	- No's 5, 6, 7 & 8 (Pigmented)	47	12		325
	Trout Brood Feed	47	12		365

APPENDIX A

SUMMARY OF MAJOR PELLETED FEEDSTUFFS (JAN 1980) (CONT)

Brand	Grade	% Prot.	% Fat & Oil	% Carbohydrate	£'s Per Ton
TESS	Salmon Grower (cont)				
	- No's 4a	41	20	22	353
	Salmon Slaughter Feed				
	- No's 5, 6, 7 & 8	41	20	22	347
	- No's 5, 6, 7 & 8 (Pigmented)	41	20	22	378
	Trout Starter Feed				
	- No's 0, 1 & 2				497
	Trout Growth Feed				
	- No's 3 & 4				433
	- No's 4a				353
	Trout Slaughter Feed				
	- No's 5, 6, 7 & 8				297
	- No's 5, 6, 7 & 8 (Pigmented)				337
	Tess Meal Feeds				
	- Tess M. F. + Vitamins 10%				362
	- Tess M. F. + Vit. 10% + Pigm.				357
FULMAR	Trout Fry				
	- No's 1 & 2	53	12		570
	Fingerling				
	- No's 3	50	12		375
	Trout Grower				
	- No's 4	47	12		330
	- No's 5, 6, 7 & 8	47	12		300
	- No's 5, 6, 7 & 8 (Pigmented)	47	12		325
	Trout Brood Feed	47	12		365

APPENDIX B

EXAMPLE OF A MANUFACTURERS FEEDING GUIDE, RELATING RECOMMENDED QUANTITIES OF FEED TO SIZE OF TROUT AND TO TEMPERATURE AND TO SIZE OF TROUT (EWOS, 1979)

		Recommended Quantities of Dry Pellets per Day as Percentage of Fish Weight						
Fish Size in Inches:		1 - 1½	1½ - 2¼	2¼ - 4	4 - 6	6 - 8	8 - 10	10+
Water Temperature:								
C	F							
2	36	2.8	2.0	1.6	1.1	0.8	0.5	0.5
4	39	3.3	2.4	1.8	1.2	0.9	0.6	0.5
6	43	4.0	2.9	2.2	1.4	1.0	0.7	0.7
8	46	4.4	3.3	2.5	1.7	1.2	0.8	0.7
10	50	5.4	3.9	2.9	1.9	1.4	1.0	0.9
12	54	6.0	4.5	3.4	2.2	1.5	1.2	1.0
14	57	6.6	5.6	4.1	2.8	1.9	1.5	1.3
16	61	7.1	6.1	4.6	3.0	2.0	1.6	1.4
18	64	6.6	6.0	4.0	3.0	2.0	1.6	1.4

N.B. The above chart refers to fairly typical hard pellets containing approximately 40-45% protein. Other manufacturers produce similar guides, with very little difference between quantities of different brands. Use of wet feeds would of course necessitate considerably greater quantities to allow for the water content.

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE

Materials	Moisture %	Protein %	Source/Reference
Animal Products			
Beef - condemned meat	75.5	20.5	7, 20, 24
Beef - lips			20
Beef - liver	72.3	20.2	7, 17, 20, 24
Beef - lungs			20, 24
Beef - tripe			20, 24
Beef - spleen	75.2	18.0	7, 20, 24
Blood meal	8-14	75.3-86	4, 6, 8
Cow - udder			24
Hog - liver	72.8		12, 20, 24
Hog - lungs			24
Hog - spleen			20, 24

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Hog - stomach			24
Horse meat			20
Liver meal	7-9.5	54.3-66.5	6, 15
Meat and Bone meal	7-8	44-50.5	2, 3, 6, 10, 15, 19, 20
Poultry - by-product meal	7	57.8	15
Poultry - hydrolyzed feather meal	7	85.4	6
Sheep - liver	72.8		12, 20, 24
Sheep - tripe			20, 24
Whale meat			15
Whale meat meal	8	71.5	15
Fish Products			
Anchovy - Fresh	68.1	21.0	12

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Anchovy meal	8	65.7	15
Alewife meal	10	65.7	15
Capelin meal			5
Capelin oil			5
Carp - fresh	71-80	17.5-19	14, 15, 20
Carp meal	10	52.7	15
Cod liver oil			4
Crab meal	7-12	31.2	12, 15
Fish flour			
Fish liver meal	7	62.8	15
Fish offal			
Fish oil			
Fish solubles (dried)	8	62.4-67	6, 15

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Hake	80	17.8-18.6	14, 20
Halibut	75-79	0.5-9.6	14, 20
Herring meal	8-9	71-72.5	2, 4, 6, 12, 14, 15, 17
Horse mackerel (dried)	8.3	60.9	12
Mackerel - fresh	60-74	16-20	14
Mackerel meal			4, 12, 17
Menhaden meal	8	61.1	15
Mussel - fresh	80-84	8.9-11.7	14
Mussel meal	10	51.5	1
Mysis (dried)	-	74	17, 26, 27
Norway Pout - fresh	73-77	16	14
Peruvian fishmeal	8	66	6
Pollack oil			

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Razorfish			1
Salmon - canned	67	20.6	20, 14
Salmon - carcass	67-78	0.3-14.0	14, 20
Salmon - eggs			20
Salmon meal	7	61.5	15
Salmon viscera			20
Sand eels	73	17.8	14
Sardine meal	7	65.3	15
Shrimp meal	10	44.8-47.5	6, 15
Sole	78	18.8	14, 20
Sticklebacks - fresh			1
Stickleback meal			1
Smelt viscera and heads			20

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Tilapia (dried)			
Tuna meal	7	59.4	15
Tuna viscera			20
White fish meal	8-13	61-63	3, 6, 8, 10, 15, 17, 19, 20
Sprat	80	14.5	14
Vegetable Products			
Acorns	50	3.3	8
Alfalfa meal	7-10	15.4-22	6, 15
Barley meal	13	9.5	6
Barley middlings			3
Barley grain	10-12	9.6-12.2	15

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Beet sugar pulp	10-12	8.5-8.6	
Beet sugar molasses	22-25	6-9.5	6, 15
Brewers' dried grains	8-10.3	18.3-25.0	8, 15, 25
Cassava			
Castor bean oil meal			
Citrus dried pulp	10	6.3	15
Cetatophyllum	85.7	2.4	8
Coconut cake			
Copra meal	7	21.2	15
Corn meal			
Corn gluten meal	9-12	23-43.1	6, 15
Cottonseed meal	7-10	38-40.8	7, 10, 15, 20
Cottonseed oil cake	8	42	6

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Duckweed	93.3	2.2-3.3	25
Grass meal	10	15	4, 6
Groundnut cake	7.5-12.1	44.4-48	6, 8
Groundnut oil meal	8.5	49	6
Hay			
Ivory nut meal			
Linseed meal	9-12	34.3-37	6, 15
Linseed oil cake	10	33	6
Lupins	12-13	39-41.8	6, 8
Lupin meal			
Maize bran	11	9	6
Maize leaves	80-80.6	1.7-3.0	8
Maize meal	13	9	6

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Millet grain	11	12.1	15
Molasses			
Myriophyllum	87.4	2.4	8
Oat by-products	9	14.6	15
Oat grain	11	12.1	15
Oat hulls	7	3.6	15
Oatmeal	13	10.5	6
Peanut meal		44.8	7
Peas	11	22.4	15
Potamogeton	77.7	3.3	8
Potatoes - fresh	76.2	2.1	8
Potatoes (dried)	9	7.9	15
Rapeseed oil meal	11	36.5	6

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Rice - bran			17
Rice (ground)	11	9.6	15
Rice (polished)	11-11.3	7.2-8.4	8, 15
Rice meal	11.6	7.1	6
Rice - polishings	10	12.1	15
Rye grain	13	12.1	15
Rye meal	14	9.8	6
Sesame meal	7	44.3	15
Sesame oil cake	9	45	6
Sorghum grains	10	11.3	15
Soybean meal	10-11	42.4-48.8	3, 4, 5, 15, 19
Soya oil			4, 19
Straw			
Sugarcane molasses (dried)	10	8.4	15

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Sunflower oil meal	9-10	37-38	6
Sunflower seed meal	7	41.7-46.3	15
Sweet potato	74.6	1.3	8
Tapioca	62.4-76.9	0.4-9.4	8
Tapioca meal	13.5	2.0	6
Tabacco seed meal oil			
Water hyacinth	94.1	1.0	8
Wheat bran	11-13	14.5-15.1	4, 6, 15
Wheat germ meal	12	24.5	15
Wheat - grains	11-12	9.9-15.4	15
Wheat - middlings	11-13.5	16-16.7	3, 6, 10, 15
Wheat flour	13	11.6	15, 17, 19
Wheat meal	12-14	11-12.3	5, 6, 7

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Wheat (pre-cooked)			4, 5
Wood residues (Pinus sylvestris)		Negligible 2	1
Animals			
Asellus			1
Bloodworms	80.0	6.8-11.8	1, 8
Brine shrimp (dried)	33.2	22	12
Daphnia	93.0	3.5	1, 7
Eisenia foetida	70-75	14-16	22
Gammarus	87.5	6.4	1, 7, 21
Grasshopper flour	7.0	62.2	12
House fly maggots			1
House fly maggot meal		51.0	1

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Wheat (pre-cooked)			4, 5
Wood residues (Pinus sylvestris)		Negligible 2	1
Animals			
Asellus			1
Bloodworms	80.0	6.8-11.8	1, 8
Brine shrimp (dried)	33.2	22	12
Daphnia	93.0	3.5	1, 7
Eisenia foetida	70-75	14-16	22
Gammarus	87.5	6.4	1, 7, 21
Grasshopper flour	7.0	62.2	12
House fly maggots			1
House fly maggot meal		51.0	1

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
House fly pupae (dried)	3.9	63.1	1, 23
Locust flour	7.1	47.5	12
Lumbricus rubellus			1
Lumbricus rubellus meal			1
Lumbricus terrestris			1
Lumbricus terrestris meal		57.2	1
Locust - fresh	57.1	18.2	12
Sandhoppers	84.0	8.0	1
Silkworm pupae - fresh	64.6	19.1	8, 17
Silkworm pupae (dried)	8.9-10	55.9-75.4	8, 17, 26
Termites - fresh	44.5	20.4	12
Termites - (dried)	1.7	35.7	12
Tubifex (dried)	-	65.0	1, 27
Whelks	13.5	50.2	12

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Silk worm pupae	-	49.0	27
Dairy Products			
Buttermilk (condensed)	71	10.8	15
Casein (dehydratee)	10	82	7, 15
Milk (dried)	4	25.1	2, 15, 20
Skimmed milk powder	5-6	33.5-34, 36	4, 6, 10, 15, 17, 1
Whey powder	5-7	12-16.5	2, 5, 15
Other Materials			
Arginine	0	100	5, 13

APPENDIX C

PROTEIN CONTENT OF SOME COMMON, LOCAL AND POTENTIAL FEEDSTUFFS FOR USE IN AQUACULTURE (CONT)

Materials	Moisture %	Protein %	Source/Reference
Chlorella (dried)		40.0	11
Cystine	0	100	3, 13
Distillers' dried solubles	8-12	27-27.3	6, 10, 15, 20
Laminaria meal			
Lacithin			3, 4
Lysine	0	100	3
Methionine	0	100	3
Seaweed meal	11	8.8	4, 5, 15
Sucrose			5
Tryptophan	0	100	3, 13
Yeast - brewers' (dried)	7	45.1	4, 10, 15
Yeast - petroleum grown (dried)	8	47.0	15
Yeast - primary (dried)	7-10	46.5-48.0	3, 15, 20
Yeast - torula (dried)	7	47.8	5, 15

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Note: Where several sources are indicated, it may be necessary to accumulate the information given from several of the sources. It should not be considered to mean that all the sources mentioned record or agree with all the information given here.

APPENDIX D. COMPOSITION OF SOME LIVE FOODS

ORGANISM.	MOISTURE (As % of wet weight)	DRY MATTER (As % of wet weight)	PROT. (As % of D.M.)	FAT (As % of D.M.)	ASH	CARB.	ENERGY (Kcal per gm. D.M.)	Arginine	Histidine	Isoleucine	Leucine	Lycine	Methionine	Cystine	Phenylalanine	Tyrosine	Threonine	Valine	Alanine	Aspartic acid	Glutamic acid	Glycine	Proline	Serine	Tryptophan	Source
								AMINO ACIDS (As % of total amino acids).																		
Crustaceans.																										
Artemia	86.6	13.4	36.9	24.5	18.6	18.0																				3.
Cyclops Sp.	93	7	47	26	7	4	4.4																			7.
Chirocephalopsis bundyi (Fairy Shrimp)	93.1	6.9	59.5	17.2	10.1	7.0	4.2																			7.
Daphnia Magna	90	10	44.6	5.2	33.17	16.8																				6.
Daphnia pulex	90.7	9.3	49.7	16.3	19.3	4.9	3.6	5.6	2.1	5.6	8.2	8.8	2.3	0.8	4.7	4.1	5.2	6.4	6.5	10.6	14.0	5.3	5.0	5.2	-	7.
Diaptomus Sp.	92.4	7.6	58.1	24.6	5.8	3.5	4.6	6.2	2.8	4.9	7.7	7.7	2.3	1.3	4.1	6.2	4.9	5.8	7.0	10.0	14.5	5.3	4.7	4.7	-	7.
Gammarus lacustris	85.6	14.4	39.6	10.5	27.9	12.0	3.0	7.0	2.6	4.3	7.8	6.7	2.2	0.7	5.2	4.3	5.0	5.2	6.3	11.5	15.4	5.1	4.6	6.0	-	7.
Hyalella azteca	84.6	15.4	36.6	9.2	30.0	15.2	2.9	8.4	5.0	4.6	7.5	6.8	1.6	0.4	4.9	4.2	5.0	5.7	5.7	11.3	14.4	4.9	4.5	5.2	-	7.
Lepidurus couesi	89	11			5.1		5.2																			2.
Lynceus brachyurus	93	7			7.6		5.1																			2.
Krill (E.Superba) (Meal)	10.6	89.4	66.1	13.9		1.6		5.6	1.2	4.6	7.0	6.8	2.2	1.2	4.9	4.2	4.1	4.6	5.3	10.4	13.0	4.6	3.3	3.8	1.2	10.
Mayflies																										
Callibaetis (N)	76	24	54.5				6.1	4.8	1.1	4.2	7.9	5.7	2.7	0.5	5.3	6.6	5.5	6.2	9.0	10.4	14.5	5.3	5.7	6.6		2.
Damselflies																										
Coenagrion angulatum (N)	84	16	60		9.9			7.7	1.0	4.3	8.2	5.3	1.8	1.8	5.3	16½	5.5	7.0	8.9	10.2	15.9	4.5	6.5	6.0		2.
Enallagma boraele (N)	86.6	13.4	58.9	13.7	5.8	10.0	4.0	7.6	5.3	3.7	6.7	6.4	1.5	0.7	3.8	6.7	4.6	6.1	8.6	9.0	13.7	5.4	5.6	4.8		7.
Enallagma cyathigerum (N)	86.5	13.5	58.6	13.3	5.5	9.4	3.9	7.0	3.5	3.7	7.1	6.7	1.5	-	4.1	7.0	4.7	6.1	8.8	9.6	13.9	5.6	6.9	5.1		7.
Lestes congenor (N)	81	19	61.1	13.5			5.0																			2.
Lestes disjunctus (N)	76	24			6.0		5.3																			2.
Dragonflies																										
Aeshna sp. (N)	86.4	13.6	34.3	21.3	4.5	7.7	3.6	7.8	5.8	4.0	6.7	6.7	0.4	-	3.6	7.5	4.8	7.2	7.0	8.7	12.6	5.0	6.4	4.9		7.
Aeshna i. interrupta (N)	79	21			3.7		5.5																			2.
Sympetrum interum (N)	82	18			5.1		5.2																			2.
Water Boatmen																										
Callicorixa audeni (A)	64	36	64.4				5.4																			2.
Hesperocorixa michiganensis	83.2	16.8	61.2	18.7	4.2	3.7	4.3																			7.
Sigara sp.	74.6	25.4	55.5	32.8	3.2	2.4	5.3	5.8	2.7	4.6	8.6	5.7	1.0	0.5	3.9	6.1	4.7	6.9	9.2	10.2	12.9	6.0	6.3	5.0		7.

APPENDIX D (CONT.) COMPOSITION OF SOME LIVE FOODS — AMINO ACIDS (As % of total amino acids).

ORGANISM.	MOISTURE (As % of wet weight)	DRY MATTER (As % of wet weight)	PROT. (As % of D.M.)	FAT (As % of D.M.)	ASH (As % of D.M.)	CARB. (As % of D.M.)	ENERGY (Kcl per gm.D.M.)	Arginine	Histidine	Isoleucine	Leucine	Lycine	Methionine	Cystine	Phenylalanine	Tyrosine	Threonine	Valine	Alanine	Aspartic Acid	Glutamic Acid	Clycine	Proline	Serine	Tryptophan	Source
Backswimmers.																										
Flea sp.	88	12					4.8																			2.
Noctonecta kirbyi	80.0	20	73					2.7	0.0	2.1	3.8	2.2	0.3	0.5	2.3	5.9	2.5	2.6	3.6	4.7	8.3	2.2	2.6	2.6	-	2.
Beetles.																										
Agabus bifarius (N)	80	20			5.2		5.1																			2.
Gyrinus maculiventius (A)	65	35					5.9																			2.
Rhantus notatus (A)	66	34	66																							2.
Caddisflies.																										
Anabolia (L)	80	20	36.6		8.0		6.3	4.0	8.2	4.0	6.9	3.6	2.5	0.4	6.2	9.9	5.0	5.0	6.2	9.2	12.2	5.2	6.7	5.5	-	2.
Philarctus quaris (L)	70	30	40.4		4.5		5.5																			2.
Phryganea cinerea (L)	81	19			3.6		5.2																			2.
Limnephilus sp. (L)	76	24	45.9		5.9		5.3																			2.
Limnephilus rhombicus (L)	83.5	16.5			11.7		5.1																			2.
Triaenodes tarda (L)	74	26			4.2		5.3																			2.
Midges.																										
Ablabesmia pulchripennis (L)	71	29					6.1																			2.
Camtochironomus tentans (L)	89	11					5.2																			2.
Chironomus Sp. (L)	86.5	13.5	47.7	13.8	9.2	22.9	4.1	5.8	2.5	5.5	7.8	8.6	0.8	0.6	6.6	3.8	5.4	5.8	7.4	12.1	13.1	4.8	4.1	5.4		7.
Chironomus plumosus (L)	87.1	12.9	62.5	2.9	4.9	29.7		4.8	2.4				1.5	1.1		3.2									2.1	5.
Phytotendipes barbipes (L)	83	17					5.2																			2.
Psectrotanypus guttularis (L)	27					5.7																				2.
Leeches.																										
Erpobdella octoculata	62	38			5.9		5.5																			2.
Glossiphonia complanata	88	12	76.8		5.7		5.4																			2.
Nephelopsis obscura	89.5	10.5	65.7	16.4	5.3	12.4	4.6	5.5	3.2	4.7	8.1	8.4	0.6	1.1	4.6	3.8	5.0	5.3	5.7	11.7	14.8	6.7	5.6	5.1	-	7.
Theromyzon rude	79	21	67.6		4.1		5.3																			2.
Watermites.																										
Limnochares sp.	84	16			3.1		6.5																			2.

APPENDIX D (CONT.) COMPOSITION OF SOME LIVE FOODS

AMINO ACIDS (As % of total amino acids).

ORGANISM.	MOISTURE (As % of wet weight)	DRY MATTER (As % of wet weight)	PROT. (As % of D.M.)	FAT (As % of D.M.)	ASH (As % of D.M.)	CARB.	ENERGY (Kcal per gmD.M.)	Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Cystine	Phenylalanine	Tyrosine	Threonine	Valine	Alanine	Aspartic Acid	Glutamic Acid	Clycine	Proline	Serine	Tryptophan	Source
Mosquitos.																										
Aedes canadensis (P)	84	16					5.3																			2.
Flowerflies.																										
Tubifera sp. (L)							5.2																			2.
Soldierflies.																										
Stratiomys sp.	81	19			43.1		2.2																			2.
Molluscs.																										
Lymnaea stagnalis	71	29	15.0		71.4		1.3	4.0	2.0	4.0	8.0	6.0	0.0	1.0	5.0	4.0	6.0	5.0	12.0	14.0	15.0	6.0	6.0	6.0	-	2.
Mytilus edulis (Shell-free)	72	18	51.5																							
Diptera.																										
Chaoborus americanus (L)	93.7	6.3	60.9	17.8	7.1	7.7	4.3	8.1	5.1	4.9	7.6	8.3	1.3	-	4.4	4.7	4.5	5.2	6.3	10.9	16.4	3.9	4.1	4.3	-	7.
Musca domestica (L)			46	11				6.6	2.2	4.7	6.6	8.6	5.4	2.2	6.4	7.4	4.2	5.8	4.9	9.8	13.3	4.0	5.2	4.0	0.0	1.
Worms.																										
Eisenia foetida			61	8.5	9.0		4.0	6.7	2.5	4.2	7.8	7.0	3.5	3.7	3.6	2.2	4.7	4.8	-	-	-	4.7	-	4.6	-	8.
Enchytraeus albidus	82.3	17.7	70.1	14.5	5.5	9.8		5.6	1.9				1.7	1.1		3.4									1.8	5.
Lumbricus terrestris			57	9.5	10.0		4.0	8.3	2.7	5.3	8.2	8.5	4.2	2.3	4.2	3.7	4.6	5.6	4.1	10.2	15.7	5.1	3.4	5.1	0.7	1.
Tubifex sp.			56.7					7.2	3.5	4.5	8.1	8.8	2.6	1.3	5.1	3.9	5.4	5.2	6.3	11.2	13.4	4.9	3.9	5.2	1.4	9.
Micro-worms.																										
Rhabditis/Turbatrix sp.	76	24	40	19.5																						4.
Vertebrates.																										
Culaea inconstans	83.6	16.7	60.6	19.4	14.0	6.3	4.4	7.3	2.4	4.0	7.9	8.6	2.5	0.8	4.3	3.4	4.9	4.6	6.5	10.6	15.7	6.8	5.3	5.1	-	7.
Pimephales promelas	82.0	18.0	58.0	23.8	12.4	7.3	4.7	5.8	2.3	4.1	8.3	9.0	2.3	0.6	4.3	3.4	4.8	4.4	6.5	10.8	15.6	7.0	6.0	5.0	-	7.
Cyprinus carpio (Fry)			41.0					6.9	3.7	3.5	7.6	8.4	2.4	-	4.5	3.5	4.1	5.7	6.1	9.6	13.3	6.2	5.9	4.4	1.4	9.

NOTE. Where several sources analyse the same organism, source No. 7 (Tabachek and Yurkowski) is used where possible, as giving average values drawn from a number of sources. Source No. 2 (Driver, Sugden and Kovach) appears to contain some inconsistencies as regards total protein content and is not used where other sources are available.

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APPENDIX E.

COMPOSITION AND PRICE OF MAJOR FEEDSTUFF COMPONENTS.

	Arginine	Cystine (+ Methionine)	Histidine	Isleucine	Leucine	Lysine	Methionine (+ Cystine)	Phenylalanine (+ Tyrosine)	Threonine	Tryptophan	Tyrosine (+ Phenylalanine)	Valine	Water	Protein	Fats and Oils	Fibre	Carbohydrate	Ash	£ per Ton	Source
Trout Requirements	2.4	1.6	0.7	0.9	1.6	2.0	1.6	2.1	0.9	0.2	2.1	1.3	-	42.0	5-10	-	10-20	-	-	6
Herring Meal	4.75	0.75	1.69	3.15	5.23	5.78	2.1	2.75	2.9	0.78	2.23	4.39	8.0	72.2	8.5	0.7	0.0	10.5	241.3	1,2
White Fish Meal	3.99	0.82	1.36	2.97	4.45	4.55	1.68	2.35	2.6	0.69	1.98	3.09	9.0	61.9	4.3	0.7	0.5	23.7	250	3,2
Mackerel Meal (Defatted)																				
Meat & Bone Meal	3.53	0.49	0.9	1.66	3.05	2.98	0.66	1.73	1.69	0.3	0.77	2.38	7.0	50.5	9.9	2.0	2.2	28.4	105	1,2
Blood Meal	3.19	1.31	3.96	0.9	10.1	5.99	0.91	5.47	3.47	1.02	1.73	6.41	8.0	75.3	1.6	1.0	8.5	5.4	251.3	1,2
Hydrolysed Feather Meal	5.44	3.84	0.51	3.56	6.46	1.63	0.48	3.41	3.63	0.52	2.29	6.05	7.0	85.4	3.0	1.2	0.0	3.5	153.3	2,1
Soya Meal(44%)	2.8	0.72	0.99	2.0	3.19	2.54	0.50	2.05	1.61	0.63	1.23	2.0	11.4	44.0	1.2	6.0	31.4	6.0	134	1
Soya Meal(49%)	3.37	0.76	1.15	2.2	3.53	2.96	0.6	2.32	1.84	0.7	1.62	2.17	10.2	48.8	1.0	3.6	31.1	5.9	162.5	1
Groundnut Meal																				
Skimmed Milk Powder	1.15	0.44	0.86	2.19	3.31	2.52	0.90	1.58	1.59	0.44	1.13	2.31	6.0	33.5	0.9	0.3	51.0	8.1	730	5,2
Milk Powder: Sweepings	0.61	-	0.62	0.88	1.20	1.50	0.40	0.88	0.68	0.28	0.88	1.16	4.0	17.1	17.7	0.5	25.8	34.9	150	5,2
Dried Whey (Low Lactose)	0.52	0.36	-	-	-	1.36	0.23	-	-	0.23	-	-	7.0	17.7	1.4	0.2	66.8	14.3	180.0	9,2
Sugar Beet Pulp	0.3	0.01	0.2	0.3	0.6	0.6	0.01	0.3	0.4	0.1	0.4	0.4	10.0	8.6	0.5	18.4	58.4	4.6	99.5	2,3
Molasses	-	-	-	-	-	-	-	-	-	-	-	-	22.0	6.0	0.1	-	62.4	8.7	95.85/ 45 Gal.	2,3
Brewer's Dry Grains	1.22	0.38	0.49	1.47	1.89	0.87	0.45	1.38	0.88	0.37	1.2	1.59	8.0	25.0	6.8	14.3	41.9	3.8	100	2,6
Distiller's dry grains & solubles	0.93	0.27	0.65	1.39	2.21	0.73	0.5	1.51	0.94	0.15	0.7	1.5	8.0	27.1	9.9	9.4	41.2	4.4	114	2,1
Grass Meal																				
Linseed Cake	2.72	0.58	0.64	1.76	1.88	1.19	0.54	1.41	1.12	0.5	0.89	1.57	9.0	34.3	5.6	8.7	36.2	5.8	156	2,3
Groundnut Cake	4.05	-	0.85	1.7	2.62	1.33	0.5	1.95	1.17	0.47	-	1.89	10.0	44.0	7.3	7.8	25.3	5.3	138.6	2,3
D.C.P.																			126.8	1

APPENDIX E. COMPOSITION AND PRICE OF MAJOR FEEDSTUFF COMPONENTS.

	Arginine	Cystine (+ Methionine)	Histidine	Isoleucine	Leucine	Lysine	Methionine (+ Cystine)	Phenylalanine (+ Tyrosine)	Threonine	Tryptophan	Tyrosine (+ Phenylalanine)	Valine	Water	Protein	Fats and Oils	Fibre	Carbohydrate	Ash	£ per Ton	Source
Wheat Bran	1.3	0.35	0.4	0.49	0.93	0.6	0.21	0.57	0.47	0.28	0.44	0.7	11.0	15.1	3.9	10.3	53.1	6.2	126.5	2,3
Wheat Flour	0.42	0.31	0.25	0.46	0.88	0.24	0.18	0.6	0.32	0.1	0.33	0.49	13.0	11.6	1.2	1.1	72.8	0.5		2
Wheat Middlings	0.87	0.22	0.36	0.7	1.09	0.67	0.2	0.64	0.53	0.22	0.39	0.77	11.0	16.7	4.6	7.0	56.5	4.5	101.3	2
Wheat Parings																			110	3
Maize	0.41	0.24	0.26	0.36	1.26	0.26	0.15	0.49	0.35	0.09	0.38	0.44	12.0	9.6	3.9	2.1	70.8	1.3	126.8	1
Maize Gluten (27%)	0.89	0.41	0.61	1.4	4.65	0.52	0.67	1.77	0.9	0.13	0.63	1.4	18.0	27	2.0	7.0	41	5.0	120.5	1
Maize (Flaked)																			159.5	4
Rapeseed																			107.3	1
Barley Grain	0.53	0.23	0.25	0.47	0.8	0.42	0.15	0.6	0.38	0.15	0.32	0.6	12.0	12.2	1.9	5.0	66.6	2.3	107.5	1,2
Oats	0.65	0.18	0.19	0.42	0.77	0.38	0.14	0.51	0.35	0.15	0.35	0.54	11.0	12.1	4.9	10.8	57.7	3.0	95	2,4
Lysine	-	-	-	-	-	100	-	-	-	-	-	-	-	100	-	-	-	-	1969.7	1
Methionine	-	-	-	-	-	-	100	-	-	-	-	-	-	100	-	-	-	-	1464.8	1
Tallow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	99.4	-	-	0.6	250	1
Cod Liver Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	1200	1
Yeast (Petrol Grown)	2.04	0.46	0.89	2.48	3.61	3.59	0.82	2.22	3.0	0.41	1.78	2.66	8.0	47.0	1.0	2.5	35.5	6.0		2
Brewer's Dried Yeast	2.20	0.50	1.10	2.10	3.20	3.00	0.70	1.81	2.10	0.50	1.50	2.30	7.0	48.0	1.2	3.2	35.5	6.9	330.0	2,10

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NOTE: For many of the items it has not been possible to obtain all the desired information from a single reference, such that a number of sources have been listed. In these instances, it should not be considered to mean that all the sources listed record or agree with all the information listed here.

APPENDIX F

DIGESTIBILITY OF SELECTED FOOD ITEMS IN RAINBOW TROUT DIETS

Item	Protein Dig. %	Fat Dig. %	Source/ Reference
Herring Meal	91.0	97.3	Cho & Slinger, 1979
White Fish Meal	88.9	(97.3)	Inaba et al, 1962
Blood Meal (Animal)	39.8	-	Cho & Slinger, 1979
Hydrolysed Feather Meal	62.3	68.0	" " "
Soya Meal	93.0	-	" " "
Skimmed Milk Powder			
Wheat Middlings	95.3	89.1	" " "
Corn Gluten	92.1	89.7	" " "
Lysine	100.0	-	
Methionine	100.0	-	
Cod Liver Oil	-	99.0	
Compound Trout Pellets	89-94 (Av. 91.5)	89-94 (Av. 91.5)	Mann, 1968
Fish Feed Organisms	91.0	91.0	" "
Dried Silkworm Pupae	86.9		Inaba et al, 1962
Dried Mysid	83.8		" " "
Cotton-seed Meal	74.5		" " "
Meat Meal (Whale)	70.0		" " "
Alfalfa Meal	87.4	70.7	Cho & Slinger, 1979
Brewers' Dried Yeast	87.9	-	" " "
Poultry By-product Meal	69.2	83.6	" " "
Dried Whey (Low Lact.)	95.8	91.8	" " "
Rapeseed Meal (Solv. Extr.)	63.8	61.4	" " "

APPENDIX G.

COMPONENT (AS % OF DRY MATTER).

ITEM		ARGININE	CYSTINE + METHIONINE	HISTIDINE	ISOLEUVINE	LEUCINE	LYSINE	PHENYLALANINE TYROSINE	THREONINE	TRYPTOPHAN	VALINE	PROTEIN	FATS & OILS	CARBOHYDRATES	PRICE. £'S PER TON OF DRY MATTER.	NOTES.
Trout Requirements		2.4	1.6	0.7	0.9	1.6	2.0	2.1	0.9	0.2	1.3 3.0	42.0	6.0 15.0	3.0 20.0		
Herring Meal (7)	X1	5.2	3.1	1.8	3.4	5.7	6.3	5.0	3.1	0.8	4.8	78.5	9.2	0.0	262.3	
Digestibility												85.0	97.3	20.0		
CONTRIB		4.42	2.63	1.53	2.89	4.84	5.35	4.25	2.63	0.68	4.08	66.72	8.95	0.0	262.3	
White Fish Meal (9)	X2	4.4	2.5	1.5	3.2	4.9	5.0	4.7	2.8	0.7	3.4	67.4	4.7	0.5	274.7	
Digestibility												88.9	97.3	20.0		
CONTRIB		3.91	2.22	1.33	2.84	4.36	4.44	4.18	2.49	0.62	3.02	59.92	4.57	0.1	274.7	
Meat and Bone Meal (7)	X3	3.4	1.1	0.9	1.6	2.9	2.8	2.3	1.6	0.3	2.3	48.4	16.0	2.4	112.9	
Digestibility												45.0	75.0	20.0		
CONTRIB		1.53	0.49	0.40	0.72	1.30	1,26	1.03	0.72	0.13	1.03	21.78	12.0	0.48	112.9	
Blood Meal (8)	X4	3.5	2.4	4.3	1.0	11.0	6.5	7.8	3.8	1.1	7.0	82.1	1.7	9.2	273.2	
												39.8	85.0	20.0		
CONTRIB		1.39	0.96	1.71	0.40	4.38	2.59	3.10	1.51	0.44	2.78	32.67	1.44	1.84	273.2	
Soya Meal 44 (11)	X5	3.1	1.3	1.1	2.2	3.5	2.8	3.6	1.8	0.7	2.2	49.2	1.3	35.2	150.6	
Digestibility												93.0	85.0	20.0		
CONTRIB		2.88	1.21	1.02	2.04	2.35	2.60	3.35	1.67	0.65	2.05	45.76	1.11	7.04	150.7	
Soya Meal 49 (10)	X6	3.7	1.5	1.3	2.4	3.9	3.2	4.3	2.0	0.8	2.4	54.3	1.1	34.5	180.6	
Digestibility												93.0	85.0	20.0		
CONTRIB		3.44	1.40	1.21	2.23	3.62	2.89	4.00	1.86	0.74	2.23	50.5	0.93	6.90	180.6	
Skim Milk Powder (6)	X7	1.2	1.4	0.9	2.3	3.5	2.6	2.8	1.7	0.5	1.2	35.5	1.0	54.0	776.6	
Digestibility												90.0	85.0	50.0		
CONTRIB		1.08	1.26	0.81	2.07	3.15	2.34	2.52	1.53	0.45	1.08	31.95	0.85	27.0	776.6	
Brewer's Dried Grain (8)	X8	1.3	0.9	0.5	1.6	2.0	0.9	2.8	0.9	0.4	1.7	27.2	7.4	45.6	108.7	
Digestibility												90.0	85.0	20.0		
CONTRIB		1.17	0.81	0.45	1.44	1.80	0.81	2.52	0.81	0.36	1.53	24.48	6.29	9.12	108.7	
Wheat Bran (11)	X9	1.1	0.6	0.4	0.5	1.0	0.7	1.0	0.5	0.2	0.8	16.9	4.3	59.4	142.1	
Digestibility												90.0	85.0	20.0		
CONTRIB		0.99	0.54	0.36	0.45	0.9	0.63	0.9	0.45	0.18	0.72	15.21	3.66	11.88	142.1	
Dried Milk (Sweepings) (4)	X10	0.6	0.4	0.6	0.9	1.2	1.5	1.8	0.7	0.3	1.2	19.5	18.4	26.8	154.0	
Digestibility												90.0	85.0	50.0		
CONTRIB		0.54	0.36	0.54	0.81	1.08	1.35	1.62	0.63	0.27	1.08	17.55	15.14	13.4	156.0	
Wheat Midddlings (11)	X11	0.9	0.4	0.4	0.7	1.1	0.7	1.1	0.6	0.2	0.8	18.7	5.1	62.7	113.8	
Digestibility												90.0	85.0	20.0		
CONTRIB		0.81	0.36	0.36	0.63	0.99	0.63	0.99	0.54	0.18	0.72	16.83	4.33	12.54	113.8	

APPENDIX G.

ITEM		ARGININE	CYSTINE + METHIONINE	HISTIDINE	ISOLEUVINE	LEUCINE	LYSINE	PHENYLALANINE TYROSINE	THREONINE	TRYPTOPHAN	VALINE	PROTEIN	FATS & OILS	CARBOHYDRATES	PRICE. £'S PER TON OF DRY MATTER.	NOTES.
		COMPONENT (AS % OF DRY MATTER).														
Maize Gluten (18)	X12	1.1	1.3	0.7	1.7	5.6	0.6	2.4	1.1	0.1	1.7	32.4	2.4	49.2	146.9	
Digestibility												90.0	85.0	30.0		
CONTRIB		0.99	1.17	0.63	1.53	5.04	0.54	2.16	0.99	0.09	1.53	29.16	2.04	14.76	146.9	
Feed Barley (Grnd)(12)	X13	0.5	0.4	0.3	0.5	0.9	0.5	1.0	0.4	0.2	0.6	13.6	2.1	74.5	122.2	
Digestibility												90.0	85.0	20.0		
CONTRIB		0.45	0.36	0.27	0.45	0.81	0.45	0.9	0.36	0.18	0.54	12.24	1.70	14.9	122.2	
Oats (11)	X14	0.7	0.3	0.2	0.4	0.8	0.4	0.9	0.4	0.2	0.6	13.4	5.4	63.2	106.7	
Digestibility												90.0	85.0	20.0		
CONTRIB		0.63	0.27	0.18	0.36	0.72	0.36	0.81	0.36	0.18	0.54	12.06	4.59	12.64	106.7	
Lysine (0)	X15	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	1969.7	
Digestibility												100.0	-	-		
CONTRIB		0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	1969.7	
Methionine(0)	X16	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	1464.8	
Digestibility												100.0	-	-		
CONTRIB		0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	1464.8	
Cod Liver Oil	X17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	1200.0	
Digestibility												-	100.0	-		
CONTRIB		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	1200.0	
Dried Whey (L.L.)	X18	0.73	0.98	0.27	0.90	1.26	1.53	1.05	0.88	0.30	0.82	17.8	1.2	63.8	193.5	Nordo Feeds Ltd.
Digestibility												95.8	91.8	50.0		
CONTRIB		0.7	0.94	0.26	0.86	1.21	1.47	1.01	0.84	0.29	0.79	17.05	1.10	31.9	193.5	
Brewer's Dried Yeast (7)	X19	2.11	1.18	1.06	2.06	3.08	2.96	3.19	2.00	0.49	1.96	43.0	1.1	43.3	354.8	S.A.]
Digestibility												87.9	85.0	20.0		
CONTRIB		1.85	1.04	0.93	1.81	2.71	2.60	2.80	1.76	0.43	1.72	37.8	0.94	8.66	354.8	
Hydroliyzed Feather Meal (7)	X20	5.84	4.64	0.54	3.82	6.93	1.75	6.11	3.90	0.56	6.47	91.7	3.2	1.3	167.0	
Digestibility												62.3	68.0	0.5		
CONTRIB		3.64	2.89	0.34	2.38	4.32	1.09	3.81	2.43	0.35	4.03	57.13	2.18	0.0	167.0	

APPENDIX G.

COMPONENTS (AS % OF DRY MATTER).

ITEM	ARGININE	CYSTINE + METHIONINE	HISTIDINE	ISOLEUVINE	LEUCINE	LYSINE	PHENYLALANINE TYROSINE	THREONINE	TRYPTOPHAN	VALINE	PROTEIN	FATS & OILS	CARBOHYDRATES
ITEMS. X21.													
L. terrestris	4.73	3.71	1.54	3.02	4.67	4.85	4.50	2.62	0.4	3.19	57.0	9.5	0.0
90% Digestibility (Protein)	4.26	3.34	1.39	2.72	4.20	4.37	4.05	2.36	0.36	2.87	51.3	8.08	0.0
80% " " "	3.78	2.97	1.23	2.42	3.74	3.88	3.61	2.10	0.32	2.56	45.66	8.08	0.0
E. foetida	4.09	4.39	1.53	2.52	4.76	4.27	3.54	2.87	0.0	2.93	61.0	8.5	0.0
90% Digestibility	3.68	3.95	1.38	2.27	4.28	3.84	3.19	2.58	0.0	2.64	54.9	7.23	0.0
80% " " "	3.28	3.52	1.23	1.81	3.81	3.42	2.84	2.30	0.0	2.35	48.86	7.23	0.0
Tubifex Sp.	4.08	2.21	1.98	2.55	4.59	4.99	5.10	3.06	0.79	2.95	56.7	9.0	0.0
90% Digestibility	3.67	1.99	1.78	2.29	4.13	4.49	4.59	2.75	0.71	2.66	51.03	7.65	0.0
80% " " "	3.27	1.77	1.59	2.04	3.68	4.00	4.09	2.45	0.63	2.36	45.42	7.65	0.0
Daphnia pulex	2.78	1.54	1.04	2.78	4.08	4.37	4.37	2.58	0.0	3.18	49.7	16.3	4.9
90% Digestibility	2.50	1.39	0.94	2.50	3.67	3.93	3.93	2.32	0.0	2.66	44.73	13.86	0.98
80% " " "	2.23	1.23	0.83	2.23	3.27	3.50	3.50	2.07	0.0	2.55	39.81	13.86	0.98
Gammarus lacustris	2.77	1.15	1.03	1.70	3.10	2.67	3.76	1.98	0.0	2.06	39.6	10.5	12.0
90% Digestibility	2.49	1.04	0.93	1.53	2.79	2.38	3.38	1.78	0.0	1.85	35.64	8.92	2.4
80% " " "	2.22	0.92	0.82	1.36	2.48	2.12	3.01	1.59	0.0	1.65	31.72	8.92	2.4
Chironomus Sp. (Larvae).	2.77	0.67	1.19	2.62	3.72	4.10	4.96	2.58	0.0	2.77	47.7	13.8	22.9
90% Digestibility	2.49	0.60	1.07	2.36	3.35	3.69	4.46	2.32	0.0	2.49	42.93	11.73	4.58
80% " " "	2.22	0.54	0.95	2.10	2.98	3.28	3.97	2.07	0.0	2.22	38.21	11.73	4.58
Musca domestica (Larvae).	3.04	3.50	1.01	1.97	3.04	3.96	6.35	1.93	0.0	2.67	46.0	11.0	0.0
90% Digestibility	2.74	3.15	0.91	1.77	2.74	3.56	5.71	1.74	0.0	2.40	41.4	9.35	0.0
80% " " "	2.43	2.80	0.81	1.58	2.43	3.17	5.09	1.56	0.0	2.14	36.8	9.35	0.0
Sticklebacks (Culaea Sp.)	4.42	2.00	1.45	2.42	4.78	5.21	4.67	2.97	0.0	2.79	60.6	19.4	6.3
90% Digestibility	3.98	1.8	1.31	2.18	4.3	4.69	4.2	2.67	0.0	2.51	54.54	16.49	1.26
80% " " "	3.54	1.6	1.16	1.94	3.83	4.17	3.78	2.38	0.0	2.23	48.54	16.49	1.26
Hyallella azteca	3.07	0.73	1.83	1.68	2.74	2.49	3.33	1.83	0.0	2.09	36.6	9.2	15.2
90% Digestibility	2.76	0.66	1.65	1.51	2.47	2.24	3.0	1.65	0.0	1.88	32.94	7.82	3.04
80% " " "	2.45	0.58	1.47	1.35	2.19	1.99	2.67	1.48	0.0	1.67	29.65	7.82	3.04
Diaptomus Sp.	3.60	2.09	1.63	2.85	4.47	4.47	5.98	2.85	0.0	3.37	58.1	24.6	3.5
90% Digestibility	3.24	1.88	1.47	2.56	4.02	4.02	5.38	2.56	0.0	3.03	52.29	20.91	0.7
80% " " "	.88	1.67	1.31	2.28	3.58	3.58	4.79	2.28	0.0	2.70	46.5	20.91	0.7
Krill (E. superba).	3.70	2.24	0.80	3.02	4.59	4.59	3.84	2.69	0.80	3.02	66.1	13.89	1.57
90% Digestibility	3.33	2.02	0.72	2.72	4.13	4.13	3.46	2.42	0.72	2.72	59.5	11.81	0.31
80% " " "	2.96	1.79	0.64	2.42	3.68	3.68	3.08	2.15	0.64	2.42	52.95	11.81	0.31

COMPONENTS (AS % OF DRY MATTER).

APPENDIX G.

ITEM	ARGININE	CYSTINE + METHIONINE	HISTIDINE	ISOLEUVINE	LEUCINE	LYSINE	PHENYLALANINE TYROSINE	THREONINE	TRYPTOPHAN	VALINE	PROTEIN	FATS & OILS	CARBOHYDRATES
ITEMS. X21 (CONT.)													
A.S.C.P.	1.72	0.54	0.75	1.54	2.68	1.8	3.03	2.02	0.0	2.38	41.0	1.88	21.81
90% Digestibility	1.55	0.49	0.67	1.38	2.41	1.64	2.73	1.82	0.0	2.14	36.9	1.60	4.36
80% " " "	1.38	0.43	0.60	1.23	2.15	1.46	2.43	1.62	0.0	1.91	32.8	1.60	4.36
Dichornia crassipes	1.2	0.5	0.4	1.0	1.8	1.2	1.9	1.0	0.0	1.2	21.5	3.6	28.2
90% Digestibility	1.08	0.45	0.36	0.9	1.62	1.08	1.71	0.9	0.0	1.08	19.35	3.06	5.64
Pistia stratioides	0.8	0.4	0.4	0.9	1.6	1.2	1.7	0.9	0.0	1.1	13.1	3.7	26.1
90% Digestibility	0.72	0.36	0.36	0.81	1.44	1.08	1.53	0.81	0.0	0.99	11.79	3.14	5.22
Hydrilla Sp.	0.7	0.35	0.25	0.7	1.2	0.7	1.4	0.7	0.0	0.8	18.0	3.5	32.1
90% Digestibility	0.63	0.31	0.22	0.63	1.08	0.63	1.26	0.63	0.0	0.72	16.2	2.97	6.42
A. philoxeroides	2.1	0.6	1.1	1.5	1.9	1.5	0.0	1.6	0.0	1.8	15.6	2.68	21.3
90% Digestibility	1.89	0.54	0.99	1.35	1.71	1.35	0.0	1.44	0.0	1.62	14.04	2.28	4.26

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: L. terrestris

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

Edward Baker Ltd. (Trout Foods)

Estimate: £230 per ton (meal)	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 8 % WATER	MAXIMUM VALUE (£'S PER TON FRES 73 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	3.85 (£229)	229.6	211.2	64.3
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	245.8	226.1	68.8
HERRING MEAL - 10%		213.4	196.3	59.8
WHITE FISH MEAL + 10%		229.6	211.2	64.3
WHITE FISH MEAL - 10%		229.6	211.2	64.3
MEAT AND BONE MEAL + 10%		232.1	213.5	65.0
MEAT AND BONE MEAL - 10%		227.1	208.9	63.6
	ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.			
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		208.8	192.1	58.5

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: M. domestica

Edward Baker Ltd. (trout Foods)

Estimate: £177 per ton (meal)

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 8 % WATER	MAXIMUM VALUE (£'S PER TON FRESH 80 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	5.2 (£204)	204.6	188.2	40.9
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO: 1.65/1	216.7	199.4	43.3
HERRING MEAL - 10%		192.5	177.1	38.5
WHITE FISH MEAL + 10%		204.6	188.2	40.9
WHITE FISH MEAL - 10%		204.6	188.2	40.9
MEAT AND BONE MEAL + 10%		210.3	193.5	42.1
MEAT AND BONE MEAL - 10%		198.9	183.0	39.8
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		184.2	169.5	36.8

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: *Daphnia* Sp.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 10 % WATER	MAXIMUM VALUE (£'S PER TON FRES[H]) 90 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	3.0 (£206)	206.0	185.4	20.6
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	226.5	203.9	22.7
HERRING MEAL - 10%		185.6	167.0	18.6
WHITE FISH MEAL + 10%		206.0	185.4	20.6
WHITE FISH MEAL - 10%		206.0	185.4	20.6
MEAT AND BONE MEAL + 10%		213.8	192.4	21.4
MEAT AND BONE MEAL - 10%		198.3	178.5	19.8
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		185.4	166.9	18.5

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: *Hyallella azteca*

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 10 % WATER	MAXIMUM VALUE (£'S PER TON FRES 85 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	21.9 (£137)	136.7	123.0	20.5
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	139.6	125.6	20.9
HERRING MEAL - 10%		133.9	120.5	20.1
WHITE FISH MEAL + 10%		136.7	123.0	20.5
WHITE FISH MEAL - 10%		136.7	123.0	20.5
MEAT AND BONE MEAL + 10%		143.6	131.9	21.5
MEAT AND BONE MEAL - 10%		130.1	117.1	19.5
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		124.2	111.8	18.6

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Tubifex Sp.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 8 % WATER	MAXIMUM VALUE (£'S PER TON FRES 84 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	3.9 (£212)	212.3	195.3	34.0
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	228.5	210.2	36.6
HERRING MEAL - 10%		196.2	180.5	31.4
WHITE FISH MEAL + 10%		212.3	195.3	34.0
WHITE FISH MEAL - 10%		212.3	195.3	34.0
MEAT AND BONE MEAL + 10%		214.4	197.3	34.3
MEAT AND BONE MEAL - 10%		210.2	193.4	33.6
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		193.5	178.0	31.0

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Gammarus Sp.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 10 % WATER	MAXIMUM VALUE (£'S PER TON FRES 86 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	11.0 (£151)	151.3	136.2	21.2
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	156.9	141.2	22.0
HERRING MEAL - 10%		145.6	131.0	20.4
WHITE FISH MEAL + 10%		151.3	136.2	21.2
WHITE FISH MEAL - 10%		151.3	136.2	21.2
MEAT AND BONE MEAL + 10%		158.3	142.4	22.1
MEAT AND BONE MEAL - 10%		144.4	130.0	20.2
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		134.0	120.6	18.8

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Chironomus Sp.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 10 % WATER	MAXIMUM VALUE (£'S PER TON FRES 86 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	3.8 (£183)	183.5	165.2	25.7
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	190.0	171.0	26.6
HERRING MEAL - 10%		167.1	150.4	23.4
WHITE FISH MEAL + 10%		183.5	165.2	25.7
WHITE FISH MEAL - 10%		183.5	165.2	25.7
MEAT AND BONE MEAL + 10%		190.2	171.2	26.6
MEAT AND BONE MEAL - 10%		176.3	159.0	24.7
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		165.6	149.0	23.2

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Chironomus Sp.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 10 % WATER	MAXIMUM VALUE (£'S PER TON FRES 86 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	3.8 (£183)	183.5	165.2	25.7
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	190.0	171.0	26.6
HERRING MEAL - 10%		167.1	150.4	23.4
WHITE FISH MEAL + 10%		183.5	165.2	25.7
WHITE FISH MEAL - 10%		183.5	165.2	25.7
MEAT AND BONE MEAL + 10%		190.2	171.2	26.6
MEAT AND BONE MEAL - 10%		176.3	159.0	24.7
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		165.6	149.0	23.2

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: E. *foetida*

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

Edward Baker Ltd. (Trout Foods)

Estimate: £254 per ton (meal)

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 8 % WATER	MAXIMUM VALUE (£'S PER TON FRES 75 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	4.3 (£234)	234.3	215.6	58.6
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	249.0	229.1	62.3
HERRING MEAL - 10%		219.7	202.1	54.9
WHITE FISH MEAL + 10%		234.3	215.6	58.6
WHITE FISH MEAL - 10%		234.3	215.6	58.6
MEAT AND BONE MEAL + 10%		236.2	217.3	59.1
MEAT AND BONE MEAL - 10%		232.5	213.9	58.1
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		213.0	196.0	53.3

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Culaea Sp.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 8 % WATER	MAXIMUM VALUE (£'S PER TON FRESH 84 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	2.1 (£245)	245.2	226.1	39.3
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	275.7	253.6	44.1
HERRING MEAL - 10%		215.9	198.6	34.5
WHITE FISH MEAL + 10%		245.8	226.1	39.3
WHITE FISH MEAL - 10%		245.8	226.1	39.3
MEAT AND BONE MEAL + 10%		253.3	233.0	40.5
MEAT AND BONE MEAL - 10%		238.2	219.1	38.1
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		220.8	203.1	35.3

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Krill (Euphasia superba)

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 10 % WATER	MAXIMUM VALUE (£'S PER TON FRESH 85 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	2.7 (£234)	234.7	211.2	35.2
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	257.1	231.4	38.6
HERRING MEAL - 10%		211.3	190.3	34.7
WHITE FISH MEAL + 10%		234.2	210.8	35.1
WHITE FISH MEAL - 10%		234.2	210.8	35.1
MEAT AND BONE MEAL + 10%		237.8	214.0	35.7
MEAT AND BONE MEAL - 10%		230.6	207.5	34.6
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		214.1	192.7	32.1

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Diaptomus Sp.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 10 % WATER	MAXIMUM VALUE (£'S PER TON FRESH 90 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	1.9 (£247)	247.2	222.5	24.7
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	279.6	251.6	28.0
HERRING MEAL - 10%		214.8	193.3	21.5
WHITE FISH MEAL + 10%		247.2	222.5	24.7
WHITE FISH MEAL - 10%		247.2	222.5	24.7
MEAT AND BONE MEAL + 10%		253.6	228.2	25.4
MEAT AND BONE MEAL - 10%		236.0	212.4	23.6
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		221.4	199.3	22.1

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: A.S.C.P.

ASSUMING 90% PROTEIN DIGESTIBILITY OF ITEM.

	% INCLUSION AT MAX. VALUE (D.M. BASIS)	MAXIMUM VALUE (£'S PER TON D.M.)	MAXIMUM VALUE (£'S PER TON MEAL) 7.85 % WATER	MAXIMUM VALUE (£'S PER TON FRESH) 99 % WATER
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.	34.4 (£115)	115.3	106.25	1.15
HERRING MEAL + 10%	LEUCINE/ISOLEUCINE RATIO:	109.6	101.0	1.10
HERRING MEAL - 10%		121.0	111.5	1.21
WHITE FISH MEAL + 10%		115.3	106.25	1.15
WHITE FISH MEAL - 10%		115.3	106.25	1.15
MEAT AND BONE MEAL + 10%		137.0	126.25	1.37
MEAT AND BONE MEAL - 10%		117.6	108.4	1.18
ASSUMING 80% PROTEIN DIGESTIBILITY OF ITEM.				
RAW MATERIAL COSTS AS INDICATED IN APPENDIX J.		104.6	96.4	1.05

APPENDIX H. L.P. EVALUATIONS OF TEST ITEMS.

ITEM: Aquatic plant meals (Assuming 90% digestibility) (Other prices as in Appendix J.).

	MAXIMUM VALUE (£'s per ton D.M.)	MAXIMUM VALUE (£'s per ton D.M.) 10% water	MAXIMUM VALUE (£'s per ton D.M.) 92% water
Eichornia crassipes	81.5	73.4	6.5
Pistia stratioides	67.6	60.8	5.4
Hydrilla Sp.	68.2	61.4	5.5
Alternanther philoxeroides	75.3	66.8	6.0

APPENDIX I

COST ASSUMPTIONS RELATING TO USE OF MEAT OFFALS IN SECTION 3.8

*1. Assumes supply source 10 miles distant, offals pre-packed in suitable containers for removal. Assumes petrol cost of approximately £1, running cost £0.9, labour (1 hr.) £2.50, daily delivery of 1½ - 2 tons. Cost per ton = £2.50. (Using farm's existing transport).

*2. Assumes delivery by supplier from main regional warehouse. Transport charges vary greatly between suppliers, and may be included in the feed prices quoted or may only be charged for deliveries below a certain size or for deliveries in excess of a stated distance. The charge used is an estimate for Southern and Central Scotland.

*3. Mincer costed is the Torelli SC 190/VA + hopper with a capacity of 10 tons per hour. A smaller machine might prove satisfactory, but slight variations in the price affects the overall cost of feeding offals only marginally.

*4. Depreciation over 7 years.

*5. Extra labour requirement involved in mincing and hand-feeding of offals compared with feeding pellets. Taken to be 1 extra man, full-time. Cost is cost to employer, including wages and insurance.

*6. Normal haulage rates approximately £1 per 10 miles (Motor Transport, March 1980). Thus assuming 1 weekly delivery of 10 tons from source circa 50 miles distant, cost = £50, or £5 per ton.

*7. Grinder costed is the IFM/IOZELLI frozen block grinder, capacity 7 tons per hour. Capacity is in excess to requirement, but smaller machines may not be able to manage whole frozen blocks.

*8. Estimate supplied by T. H. Wathes & Co. for cold store only. Freezing unit assumed unnecessary for short periods of storage required.

*9. Part-time labour requirement.

APPENDIX J

RAW MATERIAL PRICES USED IN MOIST PELLET FEED FORMULATIONS

(AS AT JANUARY 1981)

Material	£'s per ton dry matter
Herring Meal	300
White fish meal	297
Blood meal	333
Meat and bone meal	185
Dried whey	212
Soya bean 49%	175
Wheat middlings	125
Dried brewers' yeast	360
Cod liver oil	1,450
Vitamin binder	500

APPENDIX K INDICES USED IN UPDATING COSTS IN TABLES 3.3 AND 3.4

*1. Systems 3 and 4 based on Nicholson, 1976, updated according to appropriate indices contained in the Department of Industry's "Price Index Numbers for Current Cost Accounting, April 1980" as indicated.

*2. Index for harvesting, threshing and feed processing machinery, Jan. 1976 - Jan. 1980.

*3. Index of basic weekly wage rates, Jan. 1976 - Jan. 1980, from C.S.O. "Monthly Digest of Statistics", March 1977 and March 1981. (1.66).

*4. G.R.P. Index, Jan. 1976 to Jan. 1980. From C.S.O. "Monthly Digest of Statistics", March 1977 and March 1981. (1.66).

*5. G.R.P. Index, Detailed by items: Electricity, Jan. 1976 to Jan. 1980. From C.S.O. "Monthly Digest of Statistics", March 1977 and March 1981. (1.76).

APPENDIX L.

EXAMPLES ILLUSTRATING THE ECONOMIC POTENTIAL OF U.G.F.

Unidentified growth factors, to use the term broadly, may contribute to growth in three main ways, either singly or in combination:

-They may reduce mortality, thus increasing farm production without increasing individual productivity of the fish (eg. anti-bioticsO

-They may increase the appetite/food consumption of the fish, thus increasing the growth efficiency (eg. attractants).

-They may directly increase the growth efficiency with no attendant increase in consumption, for instance by aiding digestion or reducing activity (eg. vitamins, drugs etc.).

Each of these will have a different economic affect, illustrated here by a number of examples based on the following specific effects resulting from a hypothetical inclusion of 1% by weight of U.G.F. in the diet:

-10% increase in conversion efficiency with no change in growth and consumption reduced by 10%.

-10% increase in conversion efficiency with 10% increase in growth and consumption unchanged.

-10% increase in consumption and growt but conversion efficiency unchanged (note that this is unlikely in practice).

Note that the above examples are much simplified and do not take into account other variables assosciated with changed production levels, such as water requirements, etc. The purpose is to illustrate only the high premium that may be acceptable for U.G.F.

APPENDIX L. TABULAR ILLUSTRATION OF U.G.F. ECONOMIC POTENTIAL.

	Approx. % of costs (After Lewis, 1979) (Based on 100 t.p.a.)	Approx. cost (£'s per lb prod) (Jan. 1980)	Example 1 (£'s per lb prod)	Example 2 (£'s per lb prod)	Example 3 (£8s per lb prod)
Food costs	37.5	0.234	0.211	0.211	0.234
Other variable costs	33.7	0.211	0.211	0.211	0.211
Fixed costs	28.8	0.180	0.180	0.162	0.162
Total costs	(100.0)	0.625	0.602	0.584	0.607
Assuming value of trout (£'s per lb.).			0.70		
Production		100 tons	100 tons	110 tons	110 tons
Margin/lb production		0.075	0.092	0.116	0.093
Contribution/ann.prod. (£)		15,000	18,400	25,520	20,460
Net benefit (£)		-	3,400	10,520	5,460
Feed quantity (tons) (Ass. conv. 2/1 normally)		200	180	200	220
U.G.F. quantity (tons)			1.8	2.0	2.2
Max. value of U.G.F. (£'s per ton)			1,890	5,260	2,480

APPENDIX M

Costed examples illustrating different systems and scales of moist pellet preparation. All prices quoted are for January 1981.

Example 1

Description: Daily preparation of feed (not more than 3 tons per day at maximum summer requirements; average output 1.7 tons per day) using fresh unfrozen foods delivered on a daily basis and stock-piled dry ingredients.

Fixed Costs

Mincing: Machine Type: Torelli SC 190/VA + hopper (Max. capacity 10 tons per hour. 30 HP.)

Capital Cost:	£5,000
Depreciation Period:	7 years
Annual Depreciation Charge:	£715

Mixing: Machine Type: Alvan Blanch M45 Batch Mixer (Max. capacity 45 Cu. Ft., mincing time 10-15 mins. Output 5 tons per hour. 3 HP.)

Capital Cost:	£1,100
Depreciation Period:	10 years
Annual Depreciation Charge:	£110

Pelleting: Machine Type: Lister Farm Pelleter. (Automatic unattended run; automatic cut-off; capacity 0.15 tons per hour. 7.5 HP.)

Capital Cost:	£2,130

APPENDIX M

Example 1 (Continued)

Depreciation Period:	7 years
Annual Depreciation Charge:	£300

Cooling Hoppers: Type: Lister 3 ton cooling hopper + fan (Fan: 1 HP.)

Capital Cost:	£1,000
Depreciation Period:	10 years
Annual Depreciation Charge:	£100

Accessories: Description: Conveyor/Augurs, pellet bins, etc.

Capital Cost:	£1,000
Depreciation Period:	7 years
Annual Depreciation Charge:	£140

Freezer: Description: Not Required

Capital Cost:	-
Depreciation Period:	-
Annual Depreciation Charge:	-

Cold Storage: Description: Not Required

Capital Cost:	-
Depreciation Period:	-
Annual Depreciation Charge:	-

TOTAL ANNUAL DEPRECIATION CHARGE: £1,365

APPENDIX M

Example 1 (Continued)

Operating Cost:

Power Consumption (By Operation) (Approximate): Mincing: 1,800 KwH.

Mixing: 360 KwH. Pelleting + cooling 29,750 KwH.

Price: 3.25p per KwH. (Farm tariff after first 3,918 units - assumed to be already used in other farm operations).

Annual Cost:	£1,035

Labour Requirement and Description of Activities:

Supervision of mincing, mixing and pelleting start-up	
(Pelleting unattended run)	1 hr. per run
Cleaning Equipment	1 hr. per run

Price: £2.42 per hour. (Derived from Farm Management Pocketbook 1979, adjusted to Jan. 1981 using wage index).

Annual Cost:	£1,740

TOTAL ANNUAL OPERATING COST:	£2,775
TOTAL ANNUAL COST:	£4,140
COST PER TON OF MOIST PELLETS:	£6.90

Example 2

Description: As example 1 (daily preparation of feed) but using frozen "wet" ingredients, delivered daily or stockpiled in farm cold store.

Additional Equipment Required: Frozen Block grinder, e.g. Torelli

APPENDIX M

Example 2 (Continued)

Tozelli Frozen Block Grinder CB 22. (Max. capacity 5-6 tons per hour. 100 HP.)

Extra Capital Cost:	£22,980
Extra Annual Depreciation Charge:	£2,300 (10 years)
Extra Power: Consumption:	12,000 KwH per annum
Cost:	£420
Extra Labour: 1 hr. per batch (day). (Loading from cold store).	£870
TOTAL ANNUAL COST:	£7,730
TOTAL COST PER TON:	£12.90

Example 3

Description: As example 1 but using dry meals and water only. (e.g. Abernathy style diet).

Reduced Equipment Requirement: No mincing required.

Reduced Capital Cost:	£5,000
Reduced Annual Depreciation Charge:	£715
Reduced Power: Consumption:	1,800 KwH
Cost:	£60
Reduced Labour: 1/3 hr per batch (day).	£290
TOTAL ANNUAL COST:	£3,085
TOTAL COST PER TON:	£5.10

APPENDIX M

Example 4

Description: Feed prepared twice weekly (Max. batch size approximately 10 tons; average batch size 6 tons) using fresh unfrozen foods delivered on a twice weekly basis and stockpiled dry ingredients.

Fixed Costs

Mincing: Machine Type: Torelli SC 190/VA + hopper. (Max. capacity 10 tons per hour. 3 HP.)

Capital Cost:	£5,000
Depreciation Period:	7 years
Annual Depreciation Charge:	£715

Mixing: Machine Type: Alvan Blanch M90 Batch Mixer. (Max. capacity 90 cu. ft., mixing time 10-15 mins. Output 10 tons per hour. 5 HP.)

Capital Cost:	£1,425
Depreciation Period:	10 years
Annual Depreciation Charge:	£140

Pelleting: Machine Type: Lister Farm Pelleter. (Automatic unattended run, automatic cut-off. Capacity 0.25 tons per hour. 10 HP.)

Capital Cost:	£2,316
Depreciation Period:	7 years
Annual Depreciation Charge:	£330

Cooling Hoppers: Type: 2 X Lister 3 ton cooling hoppers + fans.

APPENDIX M

Example 4 (Continued)

(Fans 1 HP.) (Alternative filling.)

Capital Cost:	£2,000
Depreciation Period:	10 years
Annual Depreciation Charge:	£200

Accessories: Description: Conveyors, augurs, pellet bins, etc.

Capital Cost:	£1,000
Depreciation Period:	7 years
Annual Depreciation Charge:	£140

Freezer: Description: Not Required

Capital Cost:	-
Depreciation Period:	-
Annual Depreciation Charge:	-

Cold Store: Description: Not Required

Capital Cost:	-
Depreciation Period:	-
Annual Depreciation Charge:	-

TOTAL ANNUAL DEPRECIATION CHARGE: £1,525

Operating Costs:

Power Consumption (By Operation) (Approximate): Mincing: 3000 KwH.

Mixing: 600 KwH. Pelleting + cooling: 26400 KwH.

Price: £3.25p per KwH.

APPENDIX M

Example 4 (Continued)

Annual Cost:	£1,050

Labour Requirement and Description of Activities:

Supervision of mincing, mixing and pelleting start-up.

(Pelleting automatic unattended run).	1½ hrs.
Cleaning Equipment	1 hr.
Price: £2.42 per hour.	
Annual Cost:	£600

TOTAL ANNUAL OPERATING COST:	£1,650
TOTAL ANNUAL COST:	£3,125
COST PER TON OF MOIST PELLETS:	£5.25

Example 5

Description: As example 4 (Twice weekly preparation of feed) but using frozen "wet" ingredients, either delivered twice weekly or stockpiled in farm cold store.

Additional Equipment Required: Frozen Block Grinder, e.g. Torelli Tozelli Frozen Block Grinder CB 22 (Max. capacity 5-6 tons per hour. 100 HP.)

Extra Capital Cost:	£22,980
Extra Annual Depreciation Charge:	£2,300 (10 yrs)
Extra Power: Consumption:	12,000 KwH per annum
Cost:	£420
Extra Labour: 3 hours per batch (loading from cold store:	£730

APPENDIX M

Example 4 (Continued)

Annual Cost:	£1,050

Labour Requirement and Description of Activities:

Supervision of mincing, mixing and pelleting start-up.

(Pelleting automatic unattended run).	1½ hrs.
Cleaning Equipment	1 hr.
Price: £2.42 per hour.	
Annual Cost:	£600

TOTAL ANNUAL OPERATING COST:	£1,650
TOTAL ANNUAL COST:	£3,125
COST PER TON OF MOIST PELLETS:	£5.25

Example 5

Description: As example 4 (Twice weekly preparation of feed) but using frozen "wet" ingredients, either delivered twice weekly or stockpiled in farm cold store.

Additional Equipment Required: Frozen Block Grinder, e.g. Torelli Tozelli Frozen Block Grinder CB 22 (Max. capacity 5-6 tons per hour. 100 HP.)

Extra Capital Cost:	£22,980
Extra Annual Depreciation Charge:	£2,300 (10 yrs)
Extra Power: Consumption:	12,000 KwH per annum
Cost:	£420
Extra Labour: 3 hours per batch (loading from cold store:	£730

APPENDIX M

Example 5 (Continued)

TOTAL ANNUAL COST:	£6,575
TOTAL COST PER TON:	£11.0

Example 6

Description: As example 4 but using dry meals and water only (e.g. Abernathy type diet).

Reduced Equipment Requirement: No mincing required.

Reduced Capital Cost:	£5,000
Reduced Annual Depreciation Charge:	£715
Reduced Power: Consumption:	3,000 KwH per annum
Cost:	£95
Reduced Labour: 1/3 Hr. per batch	£90

TOTAL ANNUAL COSTS:	£2,235
TOTAL COST PER TON:	£2.65

Example 7

Description: Feed prepared once weekly (Max. batch size approximately 20 tons: Average batch size approximately 12 tons).

Fixed Costs

Mincing: Machine Type: Torelli SC 190/VA + hopper. (Max. capacity 10 tons: 10 tons per hour. 30 HP.)

APPENDIX M

Example 7 (Continued)

Capital Costs:	£5,000
Depreciation Period:	7 years
Annual Depreciation Charge:	£715

Mixing: Machine Type: Alvan Blanch M230 Batch Mixer. (Max. capacity 230 cu. ft., mixing time approximately 15 mins. Output 20 tons per hour. 10 HP.)

Capital Costs:	£3,310
Depreciation Period:	10 years
Annual Depreciation Charge:	£330

Pelleting: Machine Type: Lister Multi Pelleter. (Automatic unattended run: automatic cut-off: Capacity 0.6-0.7 tons per hour. 25 HP.) + High Lift Assembly.

Capital Cost:	£6,185
Depreciation Period:	7 years
Annual Depreciation Charge:	£880

Cooling Hoppers: Type: 2 X Lister 3 ton cooling hoppers + fans. (Fans 1 HP each) (Alternative Filling).

Capital Costs:	£2,000
Depreciation Period:	10 years
Annual Depreciation Charge:	£200

Accessories: Description: Conveyors, Augurs, Pellet bins, etc.

Capital Cost:	£1,500

APPENDIX M

Example 7 (Continued)

Depreciation Period: 7 years

Annual Depreciation Charge: £215

Freezer: Description: To freeze 10 tons over 24 hours. Capital cost £35,000 (See type 2) adjusted for inflation by factor of 1.18 Jan. 80-Jan. 81 freezing plant retail price index.

Capital Cost: £41,200

Depreciation Period: 10 years

Annual Depreciation Charge: £4,120

Cold Store: Description: Capacity 10 tons. (Only 10 tons requires to be frozen at any one time - remainder may be used within 3-4 days without freezing). Adjusted for inflation by factor of 1.18 as for freezing plant).

Capital Cost: £8,270

Depreciation Period: 10 years

Annual Depreciation Charge: £830

TOTAL ANNUAL DEPRECIATION CHARGE: £7,285

Operating Costs:

Power Consumption (By Operation) (Approximate): Mincing 3000 KwH: Mixing 600 KwH: Pelleting and cooling 23,400 KwH: Freezing 72,000 KwH: Cold Store 24,800 (See Section 4.1.1).

Total approximately 124,500 KwH.

APPENDIX M

Example 7 (Continued)

Price: 3.25p per KwH.

Annual Cost:	£4,360

Labour Requirement and Description of Activities:

Supervision of machines, loading of freezer and cold store.	3 hrs.
Cleaning Equipment	1½ hrs.
Price: £2.42 per hour	
Annual Cost:	£550

TOTAL ANNUAL OPERATING COST:	£4,910
TOTAL ANNUAL COST:	£12,195
COST PER TON OF MOIST PELLETS:	£20.30

Example 8

Description: As example 7 (feed prepared once weekly) but using frozen "wet" ingredients.

Additional Equipment Required: Frozen Block Grinder, e.g. Torelli Tozelli Frozen Block Grinder CB 22 (Max. capacity 5-6 tons per hour. (100 HP.)

Extra Capital Cost:	£22,980
Extra Annual Depreciation Charge:	£2,300 (10 yrs)
Extra Power: Consumption:	12,000 KwH per annum
Cost:	£420

APPENDIX M

Example 8 (Continued)

Extra Labour: 5 hrs. per batch (loading from cold store)

£600

TOTAL ANNUAL COST:	£15,515
TOTAL COST PER TON:	£25.90

Example 9

Description: As example 7 but using dry meals and water only.

Reduced Equipment Requirement: No mincing required.

Reduced Capital Cost:	£5,000
Reduced Annual Depreciation Charge:	£715
Reduced Power: Consumption:	3,000 KwH
Cost:	£95
Reduced Labour: 1/3 hr. per batch	£45

TOTAL ANNUAL COST	£11,340
TOTAL COST PER TON:	£18.90

Example 10

Description: Feed prepared once monthly (Max. batch size 80 tons: Average batch size 50 tons).

Fixed Costs

Mincing: Machine Type: Torelli SC 190/VA + hopper. (Max. capacity

APPENDIX M

Example 10 (Continued)

10 tons per hour. 30 HP.)

Capital Cost:	£5,000
Depreciation Period:	7 years
Annual Depreciation Charge:	£715

Mixing: Machine Type: Alvan Blanch M230 Batch Mixer. (Max. capacity 230 cu. ft., mixing time 15 mins. Output 20 tons per hour. 10 HP.)

Capital Cost:	£3,310
Depreciation Period:	10 years
Annual Depreciation Charge:	£330

Pelleting: Machine Type: Lister Multi Pelleter. (Automatic unattended run: automatic cut-off. Capacity 0.6-0.7 tons per hour. 25 HP.) + High Lift Assembly.

Capital Cost:	£6,185
Depreciation Period:	7 years
Annual Depreciation Charge:	£880

Cooling Hoppers: Type: 2 X Lister 3 ton cooling hoppers + Fans (Fans 1 HP each) (Alterbative Filling).

Capital Cost:	£2,000
Depreciation Period:	10 years
Annual Depreciation Charge:	£200

Accessories: Description: Conveyors, Augurs, Pellet bins, etc.

Capital Cost:	£2,700

APPENDIX M

Example 10 (Continued)

Depreciation Period: 7 years

Annual Depreciation Charge: £380

Freezer: Description: To freeze virtually whole of output. (Only 3-4 days supply may be used without freezing) - approximately 50 tons in 24 hrs.

Capital Cost: £110,730

Depreciation Period: 10 years

Annual Depreciation Charge: £11,730

Cold Store: Description: Capacity 50 tons.

Captial Cost: £20,600

Depreciation Period: 10 years

Annual Depreciation Charge: £2,060

TOTAL ANNUAL DEPRECIATION CHARGE: £16,295

Operating Costs:

Power Consumption (By Operation) (Approximate): Mincing: 3000 KwH. Mixing 600 KwH. Pelleting and Cooling 23,400 KwH. Freezing 45,900 KwH. Cold Store 34,680 KwH. Total 107,380 KwH.

Price: £3.25p per KwH.

Annual Cost: £3,500

Labour Requirement and Description of Activities:

Supervision of machines, loading of freezer and cold store.

12 hrs.

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