THE USE OF FISHERY WASTES IN THE FEEDS FOR FARMED FISH

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SUMMARY

The potential of the three methods of using fishery wastes in commercial feeds for farmed fish was investigated; the first of these is their use in semi-moist feeds.

It was found that neither the inclusion of fishery products nor the moisture content of the diet had a significant effect upon the growth rate or dry matter conversion of rainbow trout (Salmo gairdneri). In a shelf-stability trial, propylene glycol was effective as an antimycotic but had a serious, growth-depressing effect. A financial appraisal showed that no significant reductions in the cost of trout feed were possible through the use of semi-moist diets. It is concluded that there is no commercial potential of semi-moist feeds for rainbow trout at present.

The use of fishery wastes as a feeding attractant was the second method investigated. Ensiled fishery wastes were sprayed onto dry diets; no consistent improvement in intake or growth rate of rainbow trout fed such diets was apparent, and fish did not preferentially select feed from demand feeders stocked with such diets. It is concluded that there is no commercial potential at present, for the use of fishery wastes as a feeding attractant for farmed fish.

The use of fishery wastes in moist diets for Atlantic salmon was also investigated. The effect of ensilage upon the nutrients in mackerel silage was studied; no adverse effects were apparent. In a large-scale field trial, the specific growth rate of salmon was 75 per cent higher when fed a diet containing frozen and ensiled mackerel than when fed a dry diet. It was estimated that the financial returns to a salmon farmer would be improved by the use of such a diet despite its higher cost. It is concluded that moist diets for salmon do have commercial potential.

A model that predicts the growth rate and harvest size of salmonids is presented and used in the development of criteria to evaluate competing feeds for salmon and trout.

KEY WORDS : FISH-SILAGE FISHERY-WASTES MOIST-DIETS PALATABILITY SALMONIDS

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PREFACE

This study is an exercise in interdisciplinary research and a study of commercial usefulness.

The interdisciplinary nature of the research derives from the close involvement of the Department of Biological Sciences, the Management Centre, and the Interdisciplinary Higher Degrees Scheme (IHD). The IHD Scheme maintains a distinctive approach to postgraduate research, namely the need to investigate all aspects of a problem rather than only that of the supervising department (see Cochran, 1981). For this reason, two quite diverse departments within the University were involved in the supervisory team and a conscious effort was made to investigate nutritional and economic problems. Thus the thesis should be read as an exercise in interdisciplinary research.

It was also intended that the study be directed towards exploring areas of commercial usefulness, and this is reflected by the involvement of an animal and fish feed manufacturing company (Edward Baker Ltd.). The firm was able to provide practical expertise in the formulation of fish diets, and was experienced in the problems associated with the intensive culture of fish. The research was supported by Edward Baker Ltd., and by the Science and Engineering Research Council/Social Science Research Council Joint Committee.

In summary, this thesis should be read as one of applied interdisciplinary research.

CONTENTS

Contents cont... Page

Contents cont... Page

Contents cont... Page

Contents cont... Page

APPENDICES

LIST OF TABLES Page

LIST OF FIGURES

GENERAL INTRODUCTION

The reduction of fish to fish meal is a capital-intensive process requiring expensive machinery and considerable energy to convert the fish to a dry powder. Furthermore, it is a process carried out at only a few large ports in this country. Consequently, fish, or fish offal available at ports remote from a fish meal plant must either be transported long distances (which may be prohibitively costly) or wasted. Tatterson and Wignall (1976), for instance, estimate that up to 100,000 tonnes of fishery wastes are discarded annually. The loss of such a valuable protein source is particularly significant when it is appreciated that the UK imports about 75 per cent of annual fish meal requirements ; in 1979, imports of fish meal amounted to 250,000 tonnes, representing £55m at 1979 prices (Cross 1981, Sea Fisheries Statistical Tables 1979).

Hence, any method by which these fishery wastes (meaning fish not directly used for human consumption) may be more effectively used, could be of commercial importance to this country. Two approaches through which this may be achieved are explored. Firstly, a more efficient usage may be achieved by their incorporation directly in a product, thereby removing the necessity of reduction to fish meal. Secondly, an increased usage would result from the acid preservation of fishery wastes available at ports remote from a fish meal plant.

This project is concerned with the application of these two approaches to the use of fishery wastes in the feeds for farmed fish. Three distinct methods of their use are investigated, and it is for this reason that the thesis is divided into three parts, namely : in Part 1 the use of fishery wastes in a semi-moist feed; in Part 2 as a feeding attractant for rainbow trout, and in Part 3 as a major ingredient in moist diets for Atlantic salmon.

Within each part, the possible advantages and disadvantages of that particular method are presented, followed by a report of feeding trials on the growth and conversion responses of fish fed diets containing fishery wastes. A costing of such diets is also presented, and it is with the aid of this, and the results of the experimental work, that an assessment is made of the commercial potential of the particular method of the incorporation of fishery wastes.

PART I

THE USE OF FISHERY WASTES IN SEMI-MOIST RAINBOW TROUT FEEDS

CONTENTS

CHAPTER 1

FEED COSTS IN RAINBOW TROUT FARMING

1. Introduction

Rainbow trout require a large proportion of good quality animal protein in their diet, and because of this, feed is the single most important element in the cost of producing these fish. Varley (1977) has estimated the cost of feed to contribute between 29 per cent and 36 per cent of the cost of rearing trout, depending on the type of holding facility used. Boyer and Lloyd (1977) estimate these costs to be between 37 per cent and 46 per cent of the total costs. Lewis (1979) estimated that out of the 31 farms surveyed, the cost of feed averaged 35 per cent of the total costs. The differences in values attributed to food costs are due to the diverse methods used in the production of rainbow trout. Thus, proportional feed costs vary with the type of holding facility, stocking density, feeding level, temperature, etc. However, all these works agree that feed costs are the most important single cost in producing market-sized rainbow trout.

It would therefore seem that an effective way of reducing costs to a farmer would be by reducing feed costs. Other workers (e.g. Groop et al., 1976; Dabrowski and Wojno, 1977) found that one way this can be achieved is through the use of less costly protein sources. These works suggest that poultry by-products or soya bean meal, supplemented with essential amino acids, could partially or wholly replace fish meal in a trout diet without a decrease in growth rate.

However, two other methods of decreasing feed costs may also be considered. In this study, an analysis will be made of the possibility of using waste fishery products as a partial replacement for fish meal in semi-moist fish diets. Production of fish meal is an energy intensive process which is becoming increasingly expensive in real terms. The use of waste fishery products (such as filleting waste, by-catch, industrial fish) directly in a fish diet has a number of advantages. Firstly, it will reduce the dependence upon fish meal without the use of poorer quality protein. Furthermore, since the waste fish need not be processed, it is possible that its nutritive value will be higher than that of fish meal.

In addition to a lower cost, and perhaps higher nutritive value, it is also possible that the waste fish may increase the palatibility of the diet, either because of the use of a moist fish ingredient or through an increased moisture content. Experimental work conducted with the intention of assessing the nutritive value to a fish of waste fishery products directly incorporated in a semi-moist diet is examined. An estimate of the cost of such a diet is also made. These two factors, plus the storage characteristics of the diet will be used to determine the commercial potential of a semi-moist diet.

In the following sections, the literature regarding the response of fish to moist diets and to diets containing waste fish will be reviewed.

2. Response of fish to higher moisture content diets

Poston (1974) and Bromley (1980) have investigated the response of brown trout and turbot respectively to diets with different moisture contents. In both of these works, it was found that moisture had no noticeable effect on growth rate or dry matter conversion. Similarly, Bromley and Smart (1981) were unable to show any differences in growth rate of rainbow trout fed a dry control diet or a moist experimental diet once the fish had become accustomed to the diet. Trout fed on a dry compound feed, moistened compound feed and a mixture of compound feed and sprat exhibited almost identical performance in terms of growth rate and dry matter feed conversion ratio. Rasmussen (1968) concluded over a series of trials, that growth rates using a moist feed were very similar to growth rates obtained using a dry feed. Thus, it may be concluded that dietary moisture content is unlikely to affect growth rate or dry matter feed conversion of rainbow trout.

3. Response of fish to diets containing waste fish

Much of the work on practical fish nutrition in the 1950s and 1960s was devoted to producing a shelf-stable, easy to use dry pellet that produced similar or superior performance in terms of growth and conversion to the moist diets already in use (see Hublou et al.,1959; Sinnhuber et al.,1963; Hublou 1963; Phillips et al.,1963; Hastings 1968; Fowler and Banks,1969). Although these works were aimed at developing a replacement for moist feeds, they do show that moist diets can produce good growth rates and low mortalities. More recent work (Satia and Brannon,1975; Oregon Fish Commission,1976) have shown that fish filleting wastes can be substituted in the Oregon moist pellet for herring meal without significant loss in weight gain or protein utilisation.

The major disadvantage with all of the above-mentioned moist diets is that they are not shelf-stable. If such diets were to be produced commercially in this country, it would mean either that individual fish farms would need to make up the diets each day (animpractical solution) or that the diets would need to be produced centrally and both transported and stored in a frozen form (which would be too costly). Solberg (1976, 1978) investigated the possibility of producing a shelf-stable semi-moist fish feed and showed that fish responded well to such a diet in short-term trials.

Solberg envisaged the production of a semi-moist diet at the fish farm itself, an option that would be impractical in this country in view of the delivery of the moist fish element. Consequently, one must envisage the production of the diet centrally. This would allow a greater degree of flexibility in the choice of raw materials and preservatives as well as a reduction in the cost of manufacture.

The present study investigates the economic and nutritional potential of producing a semi-moist fish feed for national distribution in this country. Such a product needs to be shelf-stable for at least three months. The technology of semi-moist feeds for pets is well-researched and documented, but very little work has been carried out with fish feeds. In the next chapter, the technology of semi-moist diet production will be examined and applied to the formulation of a semi-moist fish feed. The effects of moisture and the incorporation of frozen fish in the diet upon the growth and feed conversion of rainbow trout will be studied in a later chapter. The commercial potential of semi-moist diets will be assessed when both the financial and nutritional advantages or disadvantages are analysed.

CHAPTER 2

TECHNOLOGY OF SEMI-MOIST FEEDS

1. Introduction

Microbial growth and most chemical reactions require water as a substrate. It is for this reason that dry feeds are essentially shelf-stable, why moist feeds are not shelf-stable, and why semi-moist feeds require careful formulation and essential additives to ensure that they will become shelf-stable. The technology of semi-moist feeds is complex, but of obvious importance in this work; the two most important aspects are that a feed should be able to resist both microbial decay and the oxidation of lipids. In this chapter, the literature concerning semi-moist feeds will be reviewed.

2. Micro-organisms in semi-moist feeds

An important concept in the design of a shelf-stable feed is its water activity (a_w). This is a measure of the free, unbound water that is available to support biological and chemical processes. It is water activity, not the absolute moisture content that bacteria, enzymes and chemical reactant encounter and are affected by at micro-environmental levels. Water activity may be defined as the relative humidity, divided by 100, at which the feed neither gains nor loses water to its environment. Relative humidity is the amount of water vapour present in a volume of air as a percentage of the maximum possible amount present in that volume at the same temperature. For a more detailed approach to the subject of water activity, see, for instance, Mossel and Kuijk (1955), Rockland (1969), Labuza (1971), Wolf et al.,(1972) and Karel (1973).

Most organisms occurring in feeds proliferate at high water activities (that is above 0.9) but yeasts can usually tolerate lower levels (around 0.88) and moulds lower still (around 0.80). A listing of minimal levels for the multiplication of micro-organisms is given in Leistner and Rodel (1976). In order to obtain stability with respect to moulds and yeasts without the useage of additives, water activities of 0.70 and below must be maintained, which results in a dry, unpalatable feed. Water activity values of commercially produced semi-moist petfoods are usually in the region of 0.83, and mycostats, such as potassium sorbate and propylene glycol are used to inhibit the growth of moulds and yeasts (Burrows and Barker 1976). In order to inhibit the growth of Staphylococcus aureus, water activities must be maintained below 0.85, and this represents the upper level of permissible water activity (Pawsey and Davis 1976).

Other aspects of the feed will influence the ability of the feed to resist the growth of micro-organisms. For instance, the water content of a given food may have different values dependent upon the method of preparation (see e.g. Wolf et al.,1972; Rockland,1969; Salwin,1963; Labuza,1970; Chou et al.,1973). This phenomenon is a form of hysteresis, and its effect can be quite large in many foods, but the necessity of drying the product to a lower water content and then adding moisture to obtain a product of a different water activity relation seems an uneconomic proposition for fish feed manufacture.

The pH of a feed should be as low as palatability permits, since lower values tend to inhibit bacteriological production ; the value of pH has little effect upon the growth of yeasts and moulds (Leistner and Rodel,1976). However, most mould production is inhibited by a low redox potential, and for this reason, semi-moist feeds are packaged in pouches which are practically impermeable to oxygen.

Temperature has a profound effect upon storage stability (Johnson et al.,1972; Leistner and Rodel,1976; Tilbury,1976; Seiler,1976), but it is impractical to expect that storage temperatures at a fish farm will be below room temperature for all of the storage period.

Heat resistance of micro-organisms increases somewhat with decreasing water activity, and for this reason it is advisable to pre-cook the wet ingredients of a semi-moist product (Labuza,1974; Leistner and Rodel,1976).

It may be concluded that the growth of micro-organisms may be prevented through the use of various additives, processes or packaging methods. However, such devices increase production costs and this must be borne in mind in studying the commercial potential of semi-moist fish feeds.

3. Oxidative Rancidity

Both Hardy (1980) and Ackman (1980) gave accounts of the chemical reactions occurring in the oxidation process. The central reaction in this process involves the abstraction of hydrogen ion from a fatty acid molecule by a peroxy radical. This reaction produces a free radical within the molecule and a hydroperoxide. The reaction is self-sustaining since the hydroperoxide can degrade to give free radicals which, in turn, combine with oxygen to produce peroxy radicals, thus completing the cycle of events.

The initial production of free radicals is brought about by enzymes or heavy metal catalysts present in the feed. Free radicals within fatty acid chains may further degrade to peroxy radicals. The terminal reaction occurs with the combination of free or peroxy radicals. The measurement of the degree of oxidation usually measures the level of hydroperoxides in foods. This measurement is known as the "peroxide value" and is a reliable indicator of oxidation in the early stages of the process (Hardy,1980).

Lipids, especially those containing polyunsaturated fatty acids, are the components of feeds most susceptible to oxidation. Unsaturated lipids included in a diet often oxidise quite rapidly because of the catalytic action of heavy metals and blood pigments which are normally present. Oxidised lipids not only form toxic components themselves, but react with proteins to lower further the nutritional value of the diet. Vitamins are also destroyed by oxidising lipids probably by chemically reacting with hydroperoxides and carbonyls formed during auto-oxidation, and by the chemical reactivity brought about by the rise in temperature accompanying the event.

Vitamins within the feed are also affected by oxidation. Thus, Fowler and Banks (1969) and a number of other workers (Woodall et al., 1964; Watanke and Hashimoto,1968; Sinnhuber et al.,1968) have shown that Vitamin E is lost during oxidation, and that a potentially fatal condition known as liver lipoid degeneration (in which the fish exhibit dark colouration, brown-yellow pigmented livers, anaemia, lethargy, abnormal kidneys and some gill clubbing) is directly associated with the feeding of rancid diets. The addition of alpha-tocopherol (Vitamin E) is effective in protecting the fish from oxidised fats.

Also, Williams (1976) reports that Vitamin C is destroyed by oxidation, and it is known that this vitamin does act as an anti-oxidant. However, there is no evidence that fish fed rancid diets will exhibit signs of Vitamin C deficiency.

The rate of oxidation can be at its highest in a system with water activity levels of a semi-moist feed (Labuza et al.,1972) and methods of controlling the rate of this reaction usually take the form of packaging in air-tight pouches, controlled atmosphere packs, or through the addition of chemical additives. Two types of additives are available : water soluble, metal-chelating agents such as EDTA or citric acid, and fat-soluble, free radical chain terminators such as BHA and BHT. Studies (Chou and Labuza,1974; Labuza et al.,1972; Chou et al.,1973) have shown that the former are more effective at water activity levels applicable to semi-moist feeds, but are inhibited by high levels of proteins - a situation reversed with the latter type. In the feed to be researched here, it is precisely the combination of high water activities and high levels of protein that are envisaged, and problems in controlling the rate of oxidation are to be expected.

4. Use of humectants and binders

Binders generally considered for use in fish foods centre around the use of gums, alginates, gelatins or celluloses. Thain and Urch (1973) reported that hydroxy-propyl methyl cellulose (HPMC) was more effective as a binder than guar gum or gelatin, and suggested that it was cheap enough for commercial use. However, these authors did not include the proportion of binder used in the diet, and the details regarding the costs of the binders tested. In other studies, Solberg (1976, 1978) concluded that HPMC was found to be less suitable than alginates. Conversely, Wood et al. (1954) found alginates unsuccessful and reported on the successful use of carboxymethyl cellulose (CMC). Wolf (1951) reported upon the use of gelatin as a suitable binder, while tapioca, Psyllium seed and vegetable gums were found unsatisfactory. The moisture content of these diets was in the region of 75 per cent.

The use of other, more easily available binders has been mentioned in other works. Phillips (1956) mentions the use of salt as a binder, though Wood et al. (1954) report that salt only acts as a binder in conjunction with other parts of the diet, such as spleen. Salt, sugar, glycerol and propylene glycol have been used as binders in semi-moist, commercially-produced dog food, and in test diets for human consumption (Kaplow,1970 ; Potter,1970; Bone,1973; Brockman,1970; Burrows, and Barker,1976). Propylene glycol, besides acting as a binder, also has advantages as an antimycotic.

The choice of binder will depend on the ingredients in the feed, the moisture content of the diet and the relative prices of the competing binders. Again it is certain that the use of binders will increase the cost of the diet.

5. Literature on semi-moist fish feed

Only one previous study (Crawford et al.,1973) has analysed the storage characteristics of a semi-moist fish feed ; these authors analysed the shelf-stability of a 25 per cent moisture diet stabilised with various levels of potassium sorbate. They concluded that microbial and yeast growths could be controlled by the addition of potassium sorbate, but that changes in the nitrogenous compounds in fishery products reduce the likelihood of successfully using a semi-moist ration as a fish feed. The application of this work is useful, but there are methods by which the nitrogenous compounds may be better stabilised, primarily through packaging and the reduction of water activity.

CHAPTER 3

FISH SILAGE

Fluctuations in the supply of fish and the waste fishery products and the remoteness of centres of supply from centres of demand mean that an inexpensive method of storage must be found. The traditional solution is to produce fish meal which is easily transported and can be stored indefinitely. But the process is expensive in both energy and capital costs, cannot cope with seasonal availability of fish, and is not suitable for small local installations. Freezing fish is also expensive, and is unsuitable for the storage of high oil species for long periods. The ensilage of fish, however, is a simple, low-cost process capable of coping with large seasonal fluctuations, and silage may be made in either large or small quantities. Its disadvantages are that it is expensive to transport, and its nutritive value and pathological effects in fish are uncertain. An investigation of its nutritive value and pathological effects are made in Chapter 14 of this report ; in the present chapter, the process of ensilage is described.

Ensilage of fish is a process which was first carried out in Finland in the 1920s and has recently attracted some attention (see, for instance, Tatterson and Windsor,1974; Mackie,1974; Jones,1975; Backoff,1976; Gildberg and Raa,1977; Strøm and Eggum,1981). The process consists of mincing fish and adding a small percentage of acid to ensure the mixture is not liable to bacterial spoilage, and to aid in the autolytic reduction of the mixture to a slurry. The amount and type of acid added varies : 3 per cent (W/W) of formic acid was used by Tatterson and Windsor (1974) and 0.75 per cent (V/W) propionic acid, plus 0.75 per cent (V/W) formic acid was used by Gildberg and Raa (1977). In almost all cases, organic acids are favoured. The mixture of minced fish and acid, plus antioxidant (if there is a significant level of oil in the fish) is well mixed to ensure an even distribution of acid and antioxidant amongst the fish. The silage is then pumped into a storage container (such as a silo) and stirred periodically to attain good mixing. The time to liquefaction will vary upon temperature and the type of fish, but in most cases will be approximately a week to a fortnight. Windsor and Thoma (1974) and Tatterson et al.,(1980) have also studied the preservation of industrial fish by dipping them in a mixture of acids, and found that the storage life before transport to meal plants can be significantly increased.

The changes which both oils and proteins undergo have been studied by a number of authors, notably McBride et al.,(1961); Tatterson and Windsor,(1979); Backoff,(1976); Gildberg and Raa,(1977) and Strøm and Eggum,(1981). Proteins and oils are broken down to free amino acids and free fatty acids respectively. Some loss of tryptophan has been reported by Backoff (1976), but is not confirmed by Strøm and Eggum (1981).

The feeding of fish silage to pigs has been studied by Rhodes (1972), Luscombe,(1973); Whittemore and Taylor,(1976); Hillyer et al. (1976) and Smith and Adamson (1976), to rats, by Stripathy et al. (1962) and Strøm and Eggum,(1981), and to chicks by March et al. (1961). Most of these trials indicate that fish silage is of comparable nutritive quality to fish meal. Secondly, since the aspect of fish taint in the flesh will not be a problem if fish silage is fed to fish, there seems to be some promise for fish silage as a nutritive source for farmed fish. The possible nutritive value of fish silage to farmed fish will be further discussed in Part 3 of this report. The pathological effects of feeding silage-based diets to farmed fish is unknown ; no published work has investigated this problem.

Fish silage, then, has the potential to be a low-cost, low capital-intensive and simple method of storing high value protein.

CHAPTER 4

EFFECT OF MOISTURE AND OF INCLUSION OF UNPROCESSED FISHERY PRODUCTS

1. Introduction

The effect of moisture and fishery waste inclusion in a semi-moist diet upon the growth rate of rainbow trout is of obvious importance. For this reason, two experiments have been conducted to gain an insight into the effect of replacing fish meal by whole, unprocessed mackerel. The first involved the use of two diets and three tanks of rainbow trout ; the second involved six diets and six tanks of rainbow trout. These two experiments are described in the following sections.

2. Experiment 1

a) Materials and Methods

The experiment was carried out in a recycling system with partial supplementation of the water ; for a more detailed description of this system see Jauncey (1979). The fish used were rainbow trout (*Salmo gairdneri*) with a mean initial weight of 59.2g. Due to a large size diversity, and in order to minimise dominance, the fish were sorted into weight classes , so the initial weights for each tank were significantly different and non-overlapping. At the start of the experiment, each tank was stocked with 30 fish, a further 8 from the same batch were taken for proximate carcase analysis. Further proximate analyses were conducted on fish removed four and eight weeks after the start of the experiment. Temperature was maintained at $12.5^{\circ}C \pm 1^{\circ}C$ and feeding was to satiation four times a day. The control diet was fed to the tank containing the intermediate sized fish and the experimental diet to the two tanks in which were separately stocked the smallest and largest fish.

Manufacture of the experimental diet was carried out on a commercial semi-moist extruder at Sudbury, Suffolk, and was composed of the following ingredients :

Minced mackerel	30%
[1]Special G fishmeal	4%
[2]Norseamink	20%
Poultry offal	5%
Sugar	5%
Salt	2.5%
Soya bean meal	31%
Mineral and vitamin supplement	2%
Potassium sorbate	0.3%
Citric acid	0.2%
Total	100%

[1]Dried, condensed fish solubles. [2]Fishmeal made from whole fish.

The control diet was Edward Baker No. 6 floating variety (stated proximate analysis = 47%protein, 6% oil). Because these diets were not formulated to similar specifications, differences in growth and carcase composition cannot be attributed to a single ingredient. However, useful insights were gained in conducting the trial and in formulating a diet with significant levels of unprocessed fish.

b) Results

The results show that the fish in one of the tanks fed the semi-moist diet grew significantly better than either the fish on the control diet or the other tank of fish fed the semi-moist diet.

A summary of the growth measurements taken during the experimental period is given in Table 1, and a plot of the average weights is given in Figure 1. Because the initial weights are different, specific growth rate is a more valid measure of weight gain than absolute weight increase, and so only specific growth rate will be used as a basis for the comparison of diets. Specific growth rate as used here and elsewhere in this study, is based on the compound interest formula. For an explanation of this, see Appendix 1.

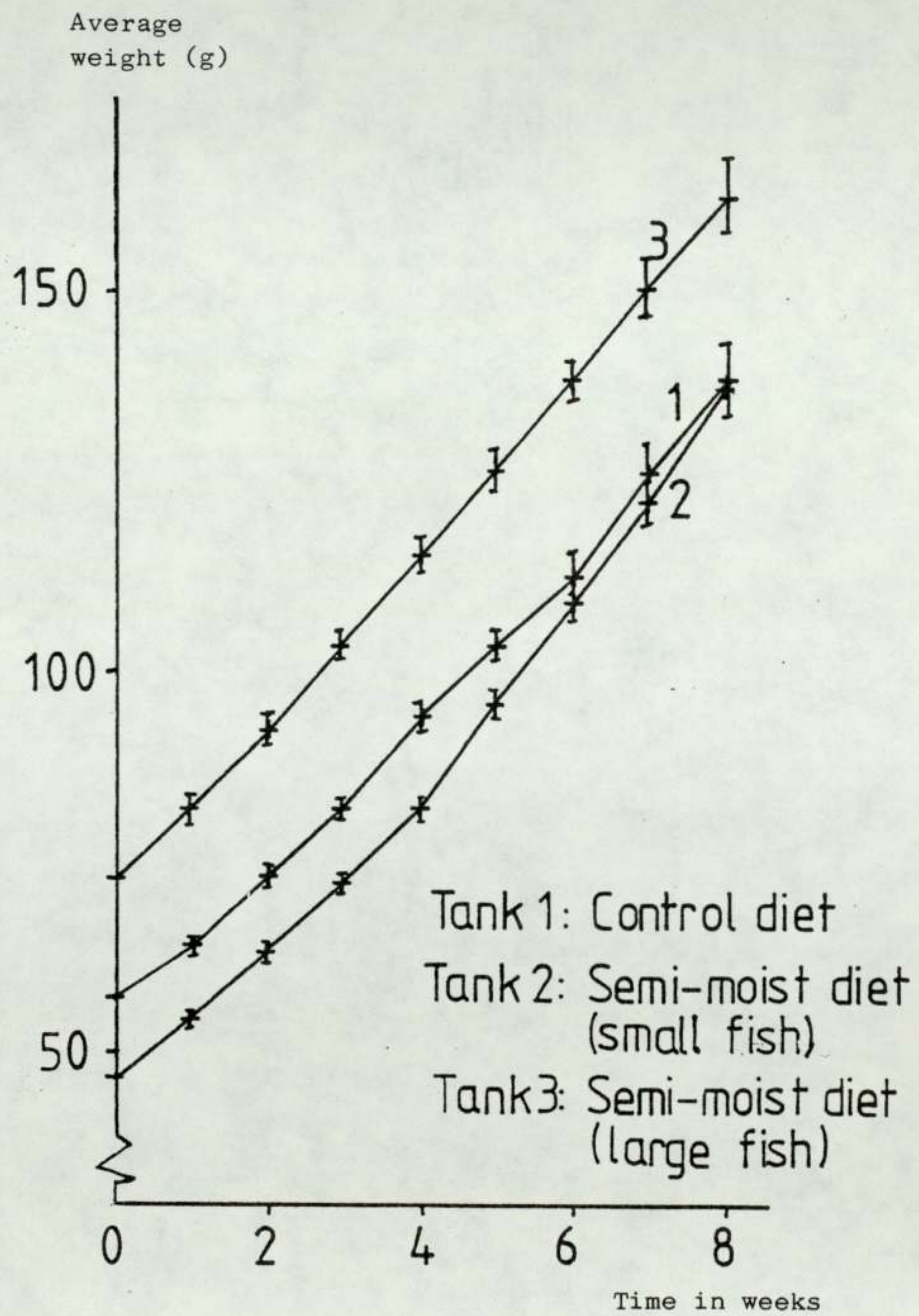
TABLE 1 : Growth rates of rainbow trout fed either a semi-moist diet or a dry commercial diet for eight weeks

Tank no.	Diet type	Average initial weight (g N=30)	Average final weight (g N=22)	Average weight increase (g N=22)	Average weekly specific growth rate N=22($\pm$S.E.)
1	Control	57.6	137.5	80.2	1.560 ± 0.056^{a}
2	Semi-moist	47.3	136.3	88.7	1.885 ± 0.036^{b}
3	Semi-moist	72.7	162.8	89.4	1.430 ± 0.038^{a}

The average weekly specific growth rate does not always compute exactly from the average initial and average final weights. For an explanation, see Appendix 2.
Different alphabetical superscripts in the final column indicate significantly different results at the .01 level, using student's t-test.

Both Figure 1 and Table 1 show that the growth rate of the fish fed the control diet is intermediate bewteen the two tanks on the experimental diet. Nor is this paradoxical result fully explained when statistical methods are used to account for the effect of the initial weight. Three separate methods were used to account for different initial weights ; they were the use of partial correlations (see Blalock,1972)the back plotting of the initial

FIGURE 1 : Average weekly weights of rainbow trout fed either an experimental, semi-moist diet, or a commercial dry diet over a period of eight weeks ± S.E.



weights (see Cowey et al.,1971; Cowey et al.,1974) and the analysis of the results of each tank using different time periods, so that the initial weight is the same for each tank. Such results indicate that there are differences at work other than dietary differences, that is, the growth of fish in tank 2 remains significantly higher than the growth of the fish in either of the other two tanks after the use of statistical analysis to account for differing initial weights. It is thought that this would most likely be due to either tank environment differences (e.g. in flow-rate, in water velocity or in noise level), and it was decided that in further experiments, the fish would be moved after each weighing to a different tank so as to help obviate any such superimposed,and so spurious results.

If the data from the two semi-moist tanks is pooled, an average specific growth rate of 1.65 $\pm$ SE 0.042 is obtained, a value that is not significantly different (at the .05 level) to that obtained for the control diet alone. The performance of the experimental diet when compared with a pellet that is designed for holding or slow-growing is disappointing, but may be due almost entirely to the high level of soya meal. More encouraging was the fact that the semi-moist pellet did not show signs of mould or bacterial growth ; the fish did not exhibit any symptoms of liver lipoid degeneration (in fact, no mortalities were recorded on any of the diets), and intake did not seem to be limited by its higher moisture content. The pellet showed good water stability properties (probably due to the good binding characteristics of soya and sugar) and did not produce excessive amounts of dust which would have been noticed at the end of a bag of feed.

There seems to be no consistent trend in differences in proximate analysis of the fish between the diets ; the control diet produced fish with a lower protein and ash content that the experimental diet-fed fish when analysed at the intermediate stage, but this difference was not apparent in the final analysis (see Appendix 2). The only noticeable difference over time is the decrease in moisture content in the final analysis.

Visceral weight was not measured separately, though gutting prior to organoleptic tests did not reveal any noticeable differences. The organoleptic tests showed that the experimental fish had a stronger taste and a redder flesh, the latter may be due to the presence of carotenoids in the experimental work.

3. Experiment 2

a) Materials and Methods

A six-tank experiment was designed to investigate simultaneously the effect of inclusion of unprocessed fishery products and increased moisture content. Six diets containing three different levels of mackerel (0%, 10% and 25%) and two different pellet types, namely : compressed dry pellets and extruded, semi-moist pellets, were fed to rainbow trout.

A recycling system was stocked with a total of 150 rainbow trout with mean initial weight of 79 grams, divided into six lots of equal number and biomass. The fish were individually tagged, weighed weekly and fed four times per day a set daily ration level on a dry weight basis. The moisture content of each diet was calculated weekly to allow for any absorption or desorption of moisture, and the feeding level was altered accordingly. To obviate tank differences, after each weighing the fish were transferred to a neighbouring tank, so that after six weeks, each population of fish had spent one week in each of the six tanks. For weeks five and six, the daily feeding on a dry matter basis was decreased from 2.5 per cent of the biomass to 2 per cent, due to a steady and noticeable decrease in consumption.

A standard common mix was prepared, divided into six lots, and to each of these was added one of three different mixtures of whole mackerel, fish meal, fish oil and maize. One mix from each of the pairs of same-constituent diets was produced as a dry pellet and the other as a semi-moist one. The ingredients in the common mix are shown in Table 2.

TABLE 2 : Composition of the common ingredients used in the examination of the effect of the inclusion of waste fish in rainbow trout feeds, pelletised by two different methods

Norseamink (fish meal)[1]	290kg
Special G fishmeal[2]	80
Blood meal	50
Meat meal	50
Maize meal	140
Dark grains maize	100
Dried skimmed milk	75
Soya bean meal	50
Mineral/vitamin mix	20
Salt	25
Potassium sorbate	3
Citric acid	2
Total	885kg

[1]Fishmeal made from whole fish [2]Dried condensed fish solubles.

Frozen mackerel was minced and pasteurised in preparation for inclusion in the diet. The moisture, lipid and protein contents of this mixture was estimated and on this basis, mackerel was included at three different levels, progressively replacing fish meal and fish oil, while maize meal was used as a bulking agent. To each 88.5kg of basic mix, the weights of the following ingredients were added :

TABLE 3 : Composition of the varied ingredients used in the examination of the inclusion of waste fish in the diets of rainbow trout, pelletised by two different methods

	Diets A & D	Diets B & E	Diets C & F
Mackerel, minced and pasteurised	-	8.54kg	21.34kg
Fish meal	6kg	3.65kg	0.13kg
Fish oil	4.5kg	3.03kg	0.63kg
Maize meal	1kg	1.18kg	1.16kg
Total	11.5kg	16.4kg	23.26kg

Because of the high level of moisture in the mackerel, these totals are not the same ; they are calculated, however, to be iso-nitrogenous and iso-calorific on a dry weight basis. On the basis of using thawed, untreated mackerel, diets A and D represent an inclusion level of 0 per cent mackerel, B and E a level of 10 per cent, and C and F a level of 25 per cent.

The dry diets were ground and mixed separately, using the same mill employed to prepare the common mix. Approximately 40kg of each diet pair was removed and pelleted in dry form ; the sample collected for use in the experiment was taken in the middle to later stages of the pelletisation process so that contamination from the feed used previously on the machine did not occur.

After removing the amount necessary for the dry pelletisation, enough water was added and mixed to produce a dough sufficiently moist for use on the semi-moist line. The dough was transferred to the semi-moist production line, where it was fed into the system and pelletised as a semi-moist product. The dry diets will be referred to as A, B and C (0%, 10% and 25% mackerel respectively), and the semi-moist diets as D, E and F (also 0%, 10% and 25% mackerel respectively).

The following table represents the results of proximate analysis conducted upon each of the diets. All figures are on a dry matter basis.

TABLE 4 : Proximate analysis of the diets used in the examination of the effect of the inclusion of waste fish in rainbow trout diets pelletised by two different methods

Diet	Percentage levels (dry weight basis)				Percentage moisture on an as-fed basis
	Protein	Oil	Ash	N.F.E.	
A	44.29	12.06	13.16	25.54	8.33
B	47.97	11.04	13.43	27.20	12.25
C	47.75	11.85	13.57	26.83	16.55
D	48.91	10.79	13.37	26.93	27.90
E	47.97	10.63	13.55	27.85	28.45
F	49.02	10.67	13.09	27.22	27.53

Protein : Kjeldahl method, N x 6.25
Oil : Ether extraction
Ash : 24 hours at 450°C
Moisture : 24 hours at 105°C
NFE (Nitrogen Free Extract : By difference)

All analysis conducted by Aynsome Laboratories, Cumbria.

For quick reference, Table 5 gives the coding of each diet used in this experiment.

TABLE 5 : The coding of diets used in the examination of the effect of the inclusion of waste fish in rainbow trout diets, pelletised by two different methods.

		Level of mackerel inclusion 0%	10%	25%
Pelletisation process used	DRY	A (8%)	B (12%)	C (17%)
	SEMI-MOIST	D (28%)	E (28%)	F (28%)

Figure in brackets gives approximate moisture content of each diet.

b) Mortalities

In the second week, one of the fish on diet A had lost weight and showed signs of extreme subordinance (lesions, fin nipping) and displayed complete lack of appetite, and for this reason it was removed from the experiment. In the fourth week of the experiment, a failure in the supply of the make-up water in one of the systems led to a lowering of dissolved oxygen content, resulting in the death of three fish on diet D, and one on diet E.

c) Storage-stability of the diets

From the second week, noticeable levels of mould appeared, first on the semi-moist diet with the highest levels of mackerel (diet F) and was soon followed by similar growths on diet E and, a little later, on diet D. By the end of the experiment, all three semi-moist diets showed levels of mould growths, though much denser growths occurred with the highest levels of mackerel inclusion. No decrease in the appetite of the fish fed these diets was apparent, but in the final (sixth) week of the experiment, the following mortalities occurred for each of the stated diets :

Diet	Mortalities
D	4
E	7
F	8

Total viable counts, mould and yeast growths were conducted on samples of each of the above feeds, but the results were often inconsistent with visual observations, and varied considerably from week to week. This was probably due to sampling error, but the data are reported in Appendix 3.

Examination of the fish showed bronze-coloured livers with rounded edges, and since the mortalities that occurred were in accordance with the development of moulds on the diet, it was concluded that the likely cause of death was mycotoxins in these diets.

Because of these mortalities during the final week, the experiment was terminated three days early, and the weighings in the fifth week are taken as the final weights. These mortalities add to the difficulties in the interpretation of the results.

d) Results

With only one exception (diet E) the growth rates of the fish were not significantly different from each other. The initial mean weights, the mean weights after five weeks and the mean specific growth rates over the five weeks, for each of the diets, are given in Table 6.

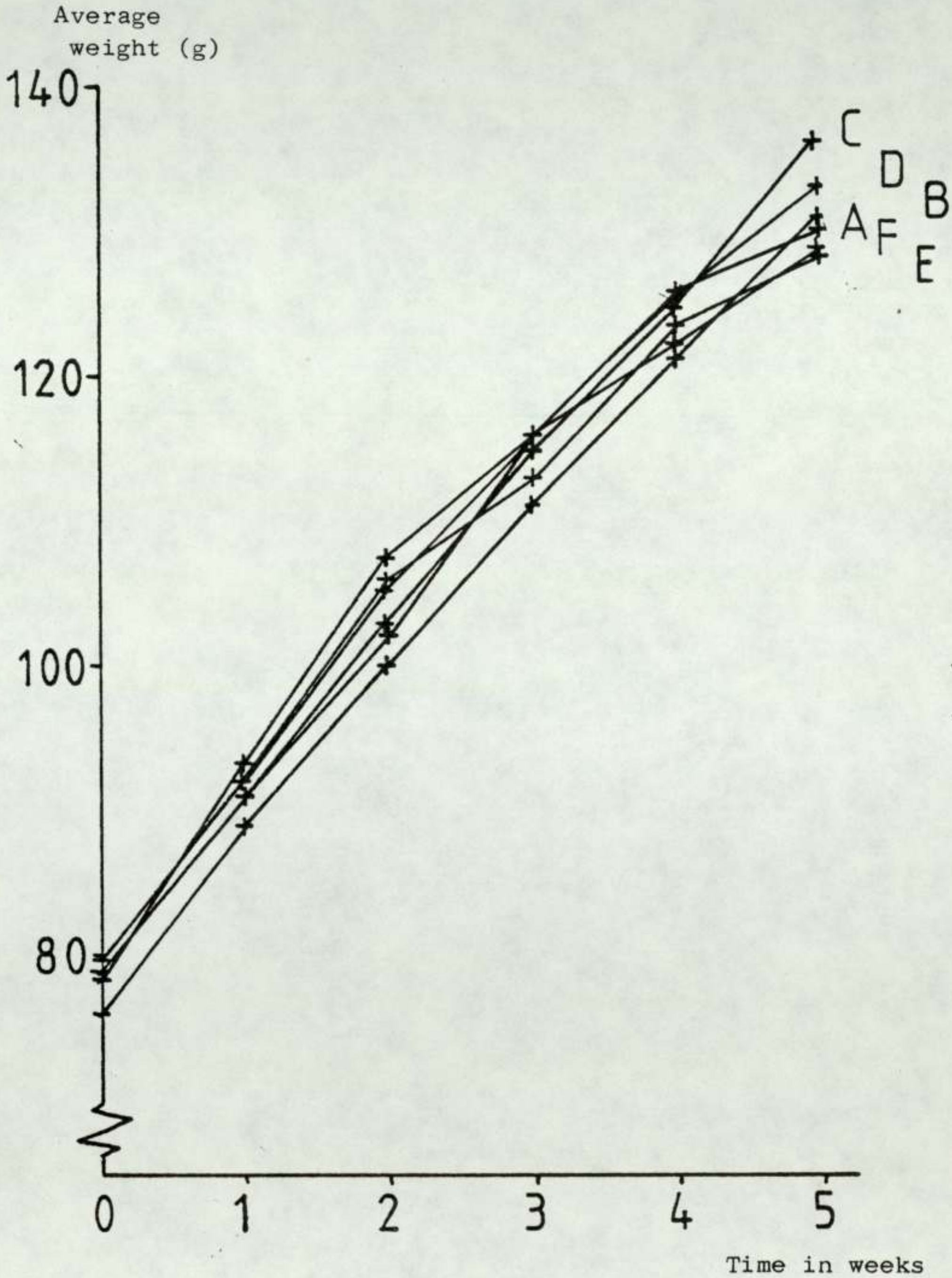
TABLE 6 : Growth indices of rainbow trout fed diets containing different levels of waste fish, pelletised by two different methods

Diet	Initial weight (g) (± SE)	Final weight (after 5 weeks) (g) (± SE)	Specific growth rate (over 5 weeks) ± SE
A	$79.2^{a} \pm 3.10$	$129.8^{a} \pm 4.6$	$1.40^{ab} \pm 0.07$
B	$77.2^{a} \pm 3.3$	$131.0^{a} \pm 5.8$	$1.51^{b} \pm 0.05$
C	$78.9^{a} \pm 3.0$	$136.1^{a} \pm 6.6$	$1.54^{b} \pm 0.06$
D	$78.5^{a} \pm 3.2$	$133.4^{a} \pm 5.5$	$1.56^{b} \pm 0.06$
E	79.7^{a} 3.2	125.8^{a} 5.9	$1.34^{a} \pm 0.07$
F	78.2^{a} 2.8	128.1^{a} 5.2	$1.41^{ab} \pm 0.06$

Common superscripts denote values not significantly different at $p = 0.05$ level using student's t-test.

The growth of fish fed diet E was significantly lower than the growth of fish fed diets B, C and D. However, as there are no other significant differences in the growth rate of the fish, and the fact that when the final mean weight is used as an index, there are no significant differences at all, it is possible that the differences that have been measured are spurious and unrelated to the diet.

FIGURE 2 : Average weekly weights of rainbow trout fed diets containing different levels of waste fish and pelletised by two different methods (see Table 5 for an explanation of the code)



The mean weekly weight for each of the diets over the five weeks are shown in Figure 2. This figure shows that the mean weekly weights of the fish closely match each other. Differences that are apparent one week are often not noticeable the next. It is thought that any differences that do occur during the course of the experiment are due to inter-tank differences. Due to transfer of fish from tank to tank during the experiment, these differences are obviated by the end of the experiment. The conversion ratios obtained with each diet are given in Table 7.

TABLE 7 : Feed conversion ratio of fish fed diets containing different levels of waste fish, pelletised by two different methods

Diet code	Feed conversion ratio (on dry weight of diet Basis)
A	1.69
B	1.54
C	1.52
D	1.59
E	1.91
F	1.73

The values obtained for the conversion ratios reflect the growth rate obtained ; this is not surprising since the fish were fed to a set body weight.

4. Conclusions

The conclusion to be drawn from these experiments is that rainbow trout can grow as well on a semi-moist diet as on an iso-nitrogenous dry diet. There seems to be neither a growth advantage nor a growth disadvantage in including unprocessed fishery products in a diet, nor in increasing the moisture content of the diet. This conclusion is consistent with the literature reviewed in Chapter 1.

The inability of the diet to withstand mould growth during storage is a serious problem, and it is one which will be examined in the following chapter.

CHAPTER 5

PRODUCTION OF A SHELF-STABLE PRODUCT

1. Introduction

Problems have arisen in the course of this work concerning the development of mould-free, shelf-stable feed. It is of obvious importance that the product is shelf-stable under normal storage conditions and the resistance of a diet to mould and yeast growth is one condition that every diet must be able to satisfy. The development of moulds and yeasts in a group of experimental diets described in the previous chapter shows that this condition has not been achieved in this case.

Consequently, an experiment was designed to assess the efficiency of an anti-mycotic propylene glycol, of proven usefulness (see Kaplow 1970, Potter 1970) on the shelf-stability of a semi-moist diet. Growth measurements of fish fed the diet were taken, and assays were conducted to determine chemical changes and bacteriological growths upon the diet. Propylene glycol was chosen, since it is in widespread use in dog feeds, and since besides acting as an anti-mycotic, it is a useful humectant. Two levels of inclusion were investigated, and the results compared with the corresponding control diet without anti-mycotic.

2. Materials and Methods

A three-tank recycling system was used, each tank stocked with fourteen rainbow trout randomly assigned to each tank. The average initial weights were similar and the fish were given one week to allow for acclimatisation to their environment and feed. Feeding level was initially set at 2 per cent of the body weight (on a dry weight basis of the feed), though this was reduced to 1 per cent for the fifth and sixth weeks. The fish were weighed fortnightly, and moved to a different tank, such that, after six weeks, each group had spent two weeks in each of the three tanks.

A common mix using the same level of ingredients as given in Table 2, Chapter 4, was made up and divided into three equal lots. The variable element was the addition of propylene glycol. Propylene glycol was added at either 0 per cent, 2.5 per cent or 5 per cent of the weight of the common mix. The diets are labelled G, H and I respectively, as summarised below.

Diet label	Level of propylene glycol added
G	None
H	2.5%
I	5.0%

The diets were stored for four weeks at room temperature before the start of the experiment to simulate the lag time between manufacture of a diet and its usage on a farm. Total viable counts, mould and yeast growths and the presence of coliforms, was recorded weekly for nine weeks. Using fortnightly intervals, three sets of measurements of peroxide values, free fatty acids and true protein were made upon each of the diets, and a proximate analysis conducted at the first of these sets.

An analysis of the data from growth measurements, and from indices of storage characteristics, allow judgements to be made as to the usefulness of propylene glycol as an anti-mycotic.

3. Growth

The addition of propylene glycol has an adverse effect on growth, even over a short period of time ; this fact is clearly shown in Figure 3, where weekly weights are plotted against time for each of the diets compounded. This is further illustrated by the table below.

TABLE 8 : Growth indices of fish fed diets containing different levels of propylene glycol for six weeks

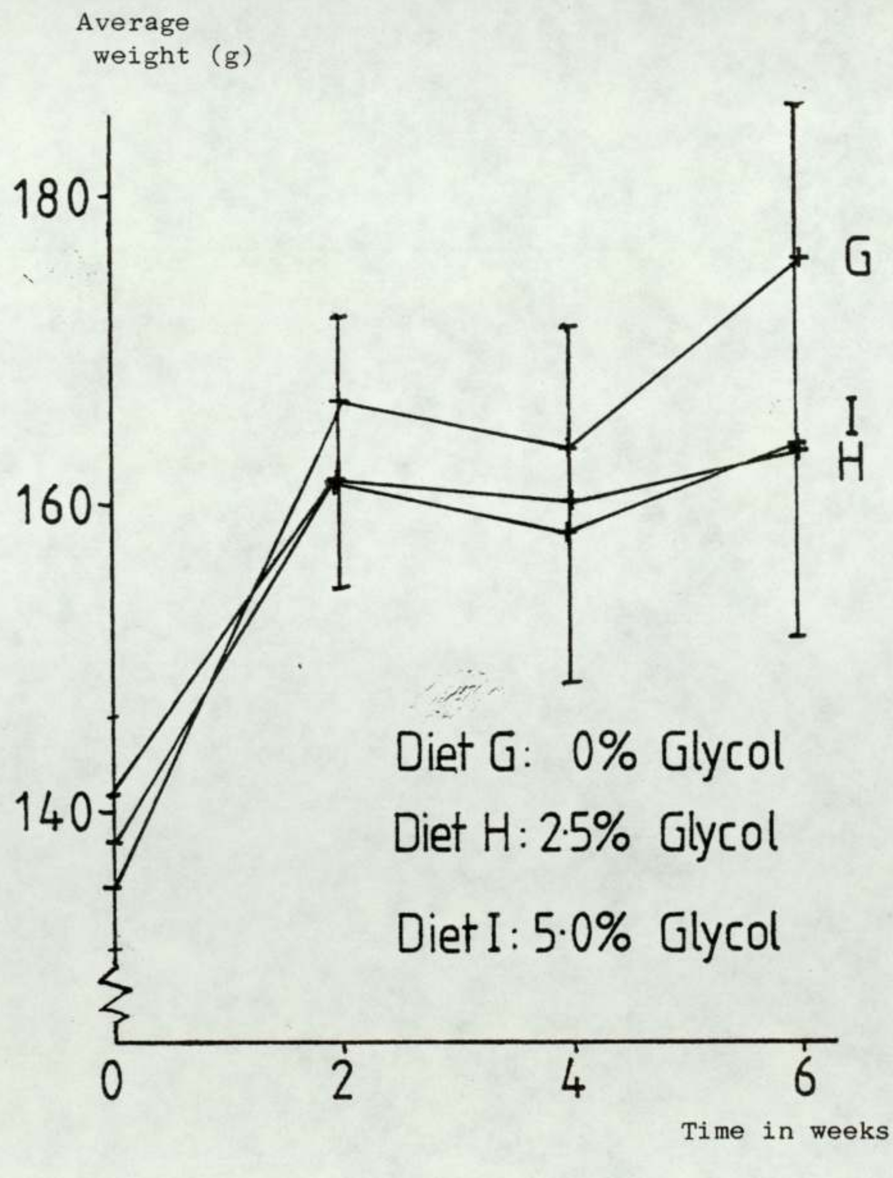
Diet code	Initial weight (g)	Final weight ± SE (g)	Specific growth rate ± SE
G	135.2	175.7 ± 10.0	0.587 ± 0.10
H	137.8	163.4** ± 12.6	0.343** ± 0.12
I	140.8	163.6* ± 5.3	0.356* ± 0.08

** Significantly different from the value of G at the .10 level using student's t-test

* Significantly different from the value of G at the .15 level using student's t-test.

Due to one mortality in each of tanks G and H, the number of cases for these tanks is 13 as opposed to 14 for diet I. The levels of significance shown in the table are not as high as might be expected due to the high standard errors for all of the diets concerned. For the first four weeks of the experiment, a high daily feeding

FIGURE 3 : Average weekly weight of rainbow trout fed diets containing different levels of propylene glycol over six weeks $\pm$ S.E



level of 2 per cent of the body weight was maintained, but some of the feed was not eaten, and due to the nature of recycling systems, a deterioration of water quality resulted in a loss of appetite and subsequent loss of weight. At the beginning of the fourth week, the feeding level was lowered to 1 per cent of the body weight and growth rates returned to normal.

Despite the loss of weight in the mid-portion of the experiment, the conlcusion that glycol does depress growth rate is clear. It is not sufficient to postulate that fish cannot metabolise the glycol, rather, that it actively inhibits the metabolic process within the fish. The reason for this growth depression is unknown, but it may be due to the glycol destroying gut bacteria within the fish.

The magnitude of the adverse effect of glycol upon growth may be seen when comparing the data of the final two weeks of the experiment. The choice of these two weeks seems the most suitable in view of the likely cause of growth depression outlined above. Without the addition of glycol, an average specific growth rate of 0.525 was maintained ; with the addition of 2.5 per cent and 5.0 per cent glycol, only 0.153 and 0.245 could be achieved. This represents a reduction in growth rate of 71 per cent and 53 per cent respectively. These results suggest that glycol is unsuitable for the incorporation into fish feed at the levels used.

Its incorporation at lower levels might reduce its adverse effect upon growth, but its wide use in semi-moist dog feeds at 2.5 per cent would imply that this level is near the minimum at which it has a useful antimycotic effect. An anti-mycotic which does not have a growth-depressing effect upon rainbow trout needs to be found if semi-moist feeds are ever to be commercially viable.

4. Storage Stability

The antimycotic effectiveness of propylene glycol was demonstrable at seven weeks after manufacture, since it was at this time that mould growths appeared upon the diet without additive. At no stage did mould appear on either of the diets stabilised with glycol, while the diet without this additive revealed increasing levels of mould growth until, some three months after manufacture, the pellets were entirely covered in a green mould. However, the fish upon diet G still accepted the pellet and showed no signs of general ill-health.

The development of the mould growth did not show up clearly in the microbial counts performed. Table 9 shows the results of the last count conducted, but prior to this, few mould counts were detected, though total viable counts showed a good deal of consistency with visual evidence. The counts taken over seven weeks (beginning three weeks after manufacture) are given in Appendix 4.

TABLE 9 : Total viable counts, mould and yeast growth and coliform presence, nine weeks after manufacture on samples of diets containing different levels of propylene glycol

Diet type	Total viable counts (counts/grams) 20°C	37°C	Moulds (c/g)	Yeasts (c/g)	Coliforms per 10ml (±)
G 0%	15,200	1,500	5,840	10	-
H 2.5%	900	1,600	600	10	-
I 5.0%	400	60	20	10	-

Total viable counts and coliforms cultivated using Ringer solution
Moulds and yeasts cultivated using malt extracts Agar.

Assays to examine any general nutritional degradation were also conducted. These took the form of an analysis of peroxide values and free fatty acids, to determine the degree of rancidity and an analysis of true protein to determine the extent of protein degradation. The results are given in Table 10 which shows that the fats do not degenerate to hydroperoxides, and that protein is not excessively degraded. However, the free fatty acids, after eight weeks of manufacture, are high and may well rise beyond these measured levels during further storage. It is probable that fish can utilise free fatty acids (Cowey and Sargent,1979), but the levels found here are nonetheless unsatisfactorily high.

In summary, we can say that though propylene glycol proved to be most effective as an anti-mycotic, its addition had a very serious growth-inhibitory effect which prohibits its usage in fish feeds.

TABLE 10 : a) Proximate analysis, four weeks after manufacture, of diets containing different levels of propylene glycol

Diet type	Protein %	Oil %	Ash %	Moisture %	Carbohydrate (bydiff) %
G	37.15	8.15	8.60	26.10	20.00
H	36.50	7.95	7.45	27.45	20.65
I	36.55	8.25	7.65	27.65	19.95

Protein : Kjeldahl method, Nx6.25
Oil : Ether extraction
Ash : 24 hours at 450°C
Moisture : 24 hours at 105°C
Carbohydrate : By difference

All analyses conducted by Aynsome Laboratories, Cumbria.

TABLE 10 : b) Fat and protein degeneration of sample diets containing different levels of propylene glycol analysed at four, six and eight weeks after manufacture

Weeks after manufacture	Peroxide value	Free fatty acids (as % of oils)	True protein (% of total feed)
	DIET G		
4	1.4	12.4	30.1
6	3.4	12.4	31.4
8	3.9	15.1	31.5
	DIET H		
4	0.4	11.9	29.3
6	3.6	13.3	31.0
8	4.0	27.4	31.2
	DIET I		
4	1.3	11.5	28.9
6	3.9	11.5	30.6
8	3.9	26.4	31.0

Peroxide value : AOAC, 12th edition, 1975, p.489. Oil extracted by Soxhlet method
Free fatty acids : AOAC, 12th edition, 1975, p.490. Oil extracted by Soxhlet method
True protein : AOAC, 12th edition, 1975, pp.130-131.

CHAPTER 6

FINANCIAL SAVINGS BY THE USE OF WASTE FISHERY PRODUCTS

1. Introduction

The production of a diet containing a significant proportion of wet fish requires an inexpensive raw material of good nutritional quality. Its supply must also be reliable, and a fairly cheap method of storage must be found.

2. Choice of Species

The price of most demersal species currently landed averages £500 per tonne (Sea Fisheries Statistical Tables 1979), and this price, therefore, excludes almost all demersal fish species as an ingredient in fish diets. It does not exclude the filleting waste from such fish ; fish filleting waste contains approximately 15 per cent protein and 0.5 per cent oil (Tatterson and Windsor,1974; Solberg,1976), and is an important source of white fish meals manufactured in this country. The price of filleting waste varies, but will be in the region of £30 per tonne ex Grimsby (personal communications, various fish wholesalers in Grimsby). It is available throughout the year in large quantities and at most fishing ports.

A second alternative is the use of industrial demersal fish such as Norway pout, sand eels and blue whiting which command much lower prices and are usually used for conversion into fish meal. Norway pout (*Trisopterus esmarkii*) is caught in the northern North Sea and landings are particularly high in the winter months (Bulletin Statistique des Peches Maritimes). They contain approximately 2 per cent oil and 17 per cent protein, and in this country are landed predominantly in the extreme north of Scotland. In 1979 (which is the latest year for which statistics are available), 3,000 tonnes were landed in Shetland and sold for an average of £29 per tonne (Scottish Sea Fisheries Statistical Tables, 1979). In the current year (1981), however, landings of Norway pout have been very low (Bannerman, personal communication), and the fish meal plant in Stornoway is now relying on sand eels, and paying very similar prices to those paid for Norway pout.

Blue whiting (Micromesistius poutassou) is caught off the Faroe Islands, and off the north-west coast of Scotland, in April, May and June. It is landed in Stornoway, Hull and Shetland (1,500 tonnes, 2,936 tonnes and 32 tonnes respectively in 1979), where it is sold for an average of £27, £102, and £24 per tonne respectively. Most of the fish are caught post-spawned and have low oil content (Svensson, 1980; I. Downie, personal communication).

Sand eels (Ammodytes spp) are caught in the North Sea (mostly in the central North Sea) usually between March and September. In 1978, 4,500 tonnes were landed at Grimsby and sold for an average price of £40 per tonne ; 3,000 tonnes were landed in Shetland in 1979 and sold for an average price of £22 per tonne. The protein and oil content of sand eels is around 17 per cent and 5 per cent respectively (Ackman and Eaton, 1971; Solberg, 1976).

A third alternative is the use of industrial pelagic fish such as sprats (Sprattus sprattus) and Atlantic mackerel (Scomber scombus); both of these species have high oil content during the landing season. Sprats are landed on the east coast of England and Scotland during the winter months (December to April), (Monthly Sea Fisheries Statistical Tables, Monthly Scottish Sea Fisheries Statistical Tables). 2,700 tonnes were landed in Grimsby in 1979 and sold at an average of £55 per tonne ; 11,538 tonnes were landed at various ports on the east coast of Scotland in 1979 and sold for an average price of £71 per tonne. The oil content of sprats varies considerably, and steadily decreases during the season. However, an average value of 14 per cent will be used (Hardy and Mackie 1969, Solberg 1978).

The landings of mackerel have increased enormously in recent years and now represent the UK's largest fishery. They are landed mostly on the north-west coast of Scotland between August and October, and on the south-west coast of England between November and March (Monthly Scottish Sea Fisheries Statistical Tables, Monthly Sea Fisheries Statistical Tables). In 1979, 82,000 tonnes were landed in Ullapool and sold for an average price of £96 per tonne, whilst 22,000 tonnes were landed in Plymouth and sold for an average price of £78 per tonne. The introduction of an intervention price has maintained the price of mackerel destined for human consumption, but this policy does not apply for mackerel unfit for human consumption, and usually destined for pet feeds or reduction to fish meal. Hence, the price for such mackerel is likely to be a good deal lower. Whole mackerel, not fit for human consumption, but adequate for reduction to fish meal sold, last season, at around £45 - £50 per tonne (personal communication, W. Donnan and Sons Ltd).

Approximately 80 per cent of the "landed" mackerel is bought at sea by foreign freezer-trawlers and taken directly to markets in Eastern Europe, the Soviet Union and Africa ; this practice (known as "Klondyking") means that only a small proportion of the mackerel catches quoted above are actually landed in this country (Fisheries of Scotland Report 1978). The oil content of mackerel varies, but is high by any standards ; it is around 28 per cent at the start of the season in Scotland, and falls to around 15 per cent by the end of the season in England.

It is obvious that there is a wide variation in the landings and prices between the different ports, and that even at the same port, the landings and prices can vary greatly over a short period. Despite this, it is possible to make some assumptions about fish availability, price and quality, and to assume that when the fluctuations in one species become too large, or price prohibitively high, it will be possible to use another species as a source of waste fish.

It is also noticeable that whilst certain fish species (such as sprats or sand eels) are available seasonally in Britain, they are landed throughout the year, or for a much wider season in other western European countries. For example, in 1976, there were five months in which no landings of sprats occurred in England, and a total of seven months (April to October inclusive) in which less than 1,000 tonnes were landed in each month. However, landings occurred throughout the year in Denmark, being at their lowest in May (2,298 tonnes) and at their highest in November (53,978 tonnes)(Bulletin Statistique des Peches Maritimes, 1979). In 1977, 135,000 tonnes of Norway pout were landed in Norway from the northern North Sea alone ; approximately 50 per cent of the tonnage was landed between the months of October and March. However, in Scotland, almost all the landings of this fish took place in this period with only 7 per cent of the annual catch landed during the "out-of-season" summer months (Bulletin Statistique des Peches Maritimes,1980).

These seasonal differences imply that the fish are available for landing, but that it becomes more costly to land, that fishing activity is transferred to other species or that demand for these two species decreases. However, I have assumed in the following evaluation that the availability and prices of fish will not change with the addition of an extra buyer. Since the extra amount of fish required for fish culture purposes in relation to the amount of fish landed is very small, this assumption seems valid.

The problem of decreasing supplies of certain fish species due to over-fishing is one that cannot be overlooked. It is a fact that aquaculture at least in its present form, cannot exist without the fishing industry upon which it so heavily depends for the feed for its stock. However, though the production of a semi-moist pellet would imply that there was a continued reliance upon the supply of industrial or waste fish, this reliance would be just as acute as the present reliance of dry fish feeds upon fish meal. The source of industrial or waste fish envisaged for use in a semi-moist product is the same source from which fish meal is made. This comprises fish filleting waste, industrial fish such as sand eels, Norway pout, blue whiting, sprats and the excess of the large quantities of mackerel currently landed. Hence, the problem of the supply of waste or industrial fish for use directly in semi-moist fish feeds will be no more acute than the supply of such fish to European fish meal manufacturers. Since the major protein source in dry fish feeds is fish meal produced in Europe, it seems unlikely that the problem of the supply of waste/ industrial fish will be more acute to a producer of semi-moist feed than to a producer of dry feeds.

In order to evaluate the usefulness of each of the above-mentioned species, it is necessary to have a standard value of fish protein and fish oil. At present, fish oil is sold at around £260 per tonne, and since it contains 100 per cent fish oil, we can say that each tonne of fish oil is worth £260. Fish meal containing around 70 per cent protein and 8 per cent oil, and sells for around £300 per tonne. One tonne of such fish meal contains 80kg of oil which is worth £20.8 (260 x 0.08). If the value of the non-protein, non-oil component of fish meal is assumed to be nil, the value of each tonne of protein in this fish meal will be approximately £400 per tonne ((300-20.8)÷0.7). A fish oil value of £260 per tonne and a fish protein value of £400 per tonne will therefore be assumed. The economic value of each fish species can now be assessed.

TABLE 11 : Net value per tonne at the port of purchase of given fish species

Source of fish	Protein content	Oil Content	Value per tonne *	Approx. price per tonne	Net value per tonne
Filleting waste	13%	0.5%	£61.3	£30	£31.3
Norway pout	17%	2%	£73.2	£40	£33.2
Blue whiting	17%	2%	£73.2	£40	£33.2
Sand eels	17%	5%	£81.0	£40	£41.0
Sprats	17%	14%	£104.4	£40	£64.4
Mackerel	17%	20%	£120	£50	£70.0

* Using a protein value of £400 per tonne and an oil value of £260 per tonne.

The prices and oil content used here are applicable to buying these species of fish at an English port and for use in animal feeds. The net value shown is therefore the net value to the buyer at the port. It does not include transport or storage costs.

3. Costs of Storage and Manufacture

As a method of storage, freezing is expensive : a price of £35 per tonne to freeze and £1.50 per tonne per month is a usual charge (Conon Bridge Cold Storage, Conon Bridge). A more sensible method of storage would be to ensile the fish until needed.

It is assumed that it is necessary to build fairly large silos : a 100M^3 silo made of steel, lined with enamel and resting on a concrete base would cost, including parts, delivery and erection, approximately £4,500 (e.g. Simplex of Cambridge Ltd., R.O. Smith Ltd.). Assuming an interest rate of 18 per cent, a pay-back period of seven years, and using the capital recovery factor (see Appendix 7), the annual storage costs (in terms of storage equipment alone) of 100 tonnes of silage is approximately £11.80 per tonne of silage. The contribution of this cost to each tonne of fish waste will be dependent upon the time for which the fish is stored (i.e. the intensity of use of the storage facilities). If it were necessary to rely solely on mackerel from S.W. England as the feed source, it would be necessary to store this for up to twelve months. This is because the storage facilities would be used only once a year ; on this basis, the storage costs of each tonne of mackerel would be £11.80 per tonne. The use of both mackerel and sand eels would mean that the storage facilities would be used twice a year since the mackerel season occurs in late autumn, while sand eels are landed during the summer. On this basis it would be necessary to store the fish for up to six months, and so the cost of storage would be £5.70 per tonne (£11.40 ÷ 2). Filleting waste is available continuously, and it would only be necessary to store it for a short while (perhaps one month). Hence, the storage costs would be approximately £1.00 per tonne (£11.40 ÷ 12).

The equipment necessary for the manufacture of the fish silage consists of a mincer, conveyor belt, pump, mixer and acid-addition machinery. The cost of the equipment necessary to process 500 tonnes per year is likely to be approximately £20,000 (Hobart Manufacturing Co. Ltd.). Assuming an interest rate of 18 per cent per annum, a payback period of seven years, and using the capital recovery factor, the cost of manufacture of each tonne of silage will be £10.50 per tonne of silage.

The addition of formic acid at 3 per cent W/W and costing approximately £600 per tonne (BP Chemicals) will add £18 to the cost of each tonne of silage made. The cost of ethoxyquin at 150ppm is assumed to be negligible, as in the labour required to manufacture the silage.

For convenience, it is assumed that the silage will be made and stored at Sudbury, Suffolk. Transport charges for fish carried on a tipper-type lorry are approximately £17 per tonne from Plymouth, and £10 per tonne from Grimsby/Hull (W.F. Miners Ltd., Plymouth). These costs are summarised in Table 12.

TABLE 12 : Net value per tonne of selected industrial and waste fish at the point of usage

Option	Net value per tonne	Storage costs per tonne	Manufacturing cost per tonne	Transport costs per tonne	Formic acid costs per tonne (of silage)	Net value of storing ensiled fish per tonne at point of use
Filleting waste	£31.3	£1.0	£10.5	£10	£18	-£8.20
Mackerel plus sand eels	£55.5	£5.7	£10.5	£13.5	£18	£7.80
Mackerel	£70.0	£11.4	£10.5	£17	£18	£13.10

4. Costs of inclusion of fishery wastes in diet

Table 12 shows that mackerel promises to be one of the most valuable species for use in semi-moist diets, despite the fact that it is expensive to transport and store. Since there is a relatively low moisture content in each tonne of mackerel, a relatively high proportion of this fish may be used in the semi-moist pellet produced. It has already been assumed to have a protein and oil content of 17 per cent and 20 per cent respectively ; if we allow a level of 2 per cent ash it implies a moisture content of 61 per cent. A semi-moist pellet should have a moisture content of around 25 per cent. If we assume the remainder of the material (fish meal, soya meal, vitamin and mineral mix, etc.) to have a moisture content of 10 per cent, we may add a maximum of 29 per cent mackerel. This is obtained by the formula :

$$(0.61X) + (1-X \times 0.1) = 0.25$$

$$X = \frac{0.15}{0.51}$$

$$= 0.29$$

Assuming that the 29 per cent mackerel added replaces exactly the nutritive value which would have been provided by fish meal, it is possible to save £3.80 (£13.10 x 0.29) on the ingredient costs of each tonne of feed.

It is necessary to add some preservatives to a semi-moist product : at the very least, 0.3 per cent potassium sorbate, which at £2,000 per tonne adds £6.00 to the cost of each tonne of feed. Hence, the savings on the nutrient costs are more than off-set by the increased cost of preservatives.

On this basis alone, it seems unlikely that semi-moist fish diets will be any cheaper than dry fish diets.

However, the cost of the total dietary ingredients are not the only area of difference between dry and semi-moist fish diets. The processing costs and profit margins in producing fish diets are also of importance. Assuming that 85 per cent of the total cost of a dry diet is from the ingredients, the cost of the ingredients of a feed sold at £320 per tonne would be £272 per tonne. The cost of the ingredients in a semi-moist diet are likely to be approximately £2 more than this : thus, £274 per tonne. Note that this figure is on the same dry weight basis as a dry feed.

It is known that it is more costly to produce a semi-moist pellet than a dry one. The process needs to be more carefully controlled, the ingredients need to be heated and the pellet allowed to cool. The problems in designing such a diet are also more complex, and there is a greater chance of a batch not being shelf-stable. It may therefore be assumed that the ingredient costs of a semi-moist diet will be in the region of 80 per cent of the total cost of producing the feed (as against 85 per cent for the dry diet). If the ingredient costs are £274 per tonne, the total cost will be £342.5.

Transport costs will also be higher with a semi-moist diet. In any batch of dry diet, approximately 90 per cent consists of nutrients and 10 per cent consists of moisture. To obtain the same amount of nutrients, 20 per cent extra of a diet containing 25 per cent moisture would have to be transported, so transport costs will be 20 per cent higher. If we assume a cost of transport of a dry diet to a farmer is £15 per tonne, this would increase transport costs to £18 per tonne. Thus, the price to a farmer of a semi-moist diet is likely to be approximately £360.80, whilst a dry diet costs approximately £335 per tonne.

The conclusion to be drawn is that it is unlikely that semi-moist feeds would be cheaper to the farmer than a dry diet. Indeed, they are likely to be more expensive. We have already seen that semi-moist diets do not produce any increase in growth rate. The disadvantages are likely to be considerable ; the time spent buying in a difficult-to-handle raw material and designing and producing a separate product are serious disadvantages. Since no significant advantage could be envisaged in the production of a semi-moist diet, it was decided to concentrate research on another potential use of fishery wastes in fish feeds. This aspect was the increase in palatibility (and so growth rate) through the use of spray-coated diets. This is examined in Part 2.

PART 2

THE USE OF FISHERY WASTES AS A SPRAY COATING ON DRY DIETS

CONTENTS

INTRODUCTION TO PART 2

In order to obtain a long shelf life, modern commercial fish diets comprise around only 10 per cent moisture and so have a hard and relatively unpalatable texture. But the qualities of a long shelf life, high palatability and an economic cost of production need not be incompatible.

By coating the pellets with an attractant sprayed onto the outside of the pellet, it is conceivable that the palatability of the pellet to the fish might increase, and so improve intake and thus, growth rate. Fishery wastes such as fish offal are inexpensive and may stimulate increased feeding levels in rainbow trout. In an ensiled form it would be shelf stable and, once filtered, is easily sprayed onto a diet. Thus a coating of ensiled fishery waste is not likely to affect adversely the storage stability of the diet, nor to affect unduly the cost of its production, but may increase growth rate.

In this part, then, the use of ensiled waste fish as an attractant, spray-coated onto the outside of a pellet, is examined. The following chapter, however, reviews the value of alternative strategies open to fish nutritionists for the improvement of rainbow trout feed and produces criteria upon which competing feeds may be judged.

CHAPTER 7

EVALUATION OF ALTERNATIVE STRATEGIES FOR THE IMPROVEMENT OF RAINBOW TROUT FEEDS

1. Introduction

Before attempting to improve commercial trout feeds, it would be valuable to know what are likely to be the returns to the trout farmer for given improvements in the performance of the feed or reductions in the cost of the diet. It is necessary to decide upon the relative effectiveness of an improvement in growth rate and a reduction of feed costs. In Chapter 1, it was assumed that because feed costs were the most important single item in producing farmed rainbow trout, a reduction in feed costs would have a large effect in decreasing costs to the farmer. Although this may be true, it is too simplistic for our purposes. Instead, it is necessary to investigate the relationship between growth rate and the time to harvest.

2. Modelling Growth Rate

The measure of growth rate employed in this work is a compound interest formula defined as i and detailed in Appendix 1. However, it is a formula that takes no account of the fact that the growth rate of fish is known to decrease with increasing size. Brett and Shelbourn (1975) have shown that for the salmonids tested, the logarithms of the growth rate decrease linearly with the increasing logarithm of the weight, and that the rate at which it decreased was very similar for each of the species tested. The authors based their findings upon the results of ten experiments over a total of four different species. Thus, in the equation they derived

$$\log_e G = a + b\log_e W \qquad ....(1)$$

(where G is specific growth rate in per cent per day and W is weight in grams) they found that b $\pm$ 2 SE was equal to -0.41 ± 0.04. However, the value of "a" varied considerably ; environmental and genetic effects will have the greatest effect on the value of this intercept.

Since we know that G is very similar to the value of i (see Appendix 1), we can express the final size (FS) of a fish after n days once given its growth rate and initial size (IS) as

$$FS \simeq IS \left\{1 + \frac{e^{(a+b\log_e IS)}}{100}\right\}^n \qquad ....(2)$$

where $$e^{(a+b\log_e IS)} = G \simeq i \qquad ....(3)$$
(from equation 1)

Using equation 2 and starting with an initial size we can compute FS in n days time, use this as a new initial size and compute a new FS. This iterative process is easier to carry out using a computer. A computer program is shown in Appendix 5 ; it is written in BASIC, giving an output of the weight of a fish at the end of the day, every thirty days, and the growth rate at that time. It requires a set of values for a, b, start size, the number of thirty-day periods, and the number of days per iteration.

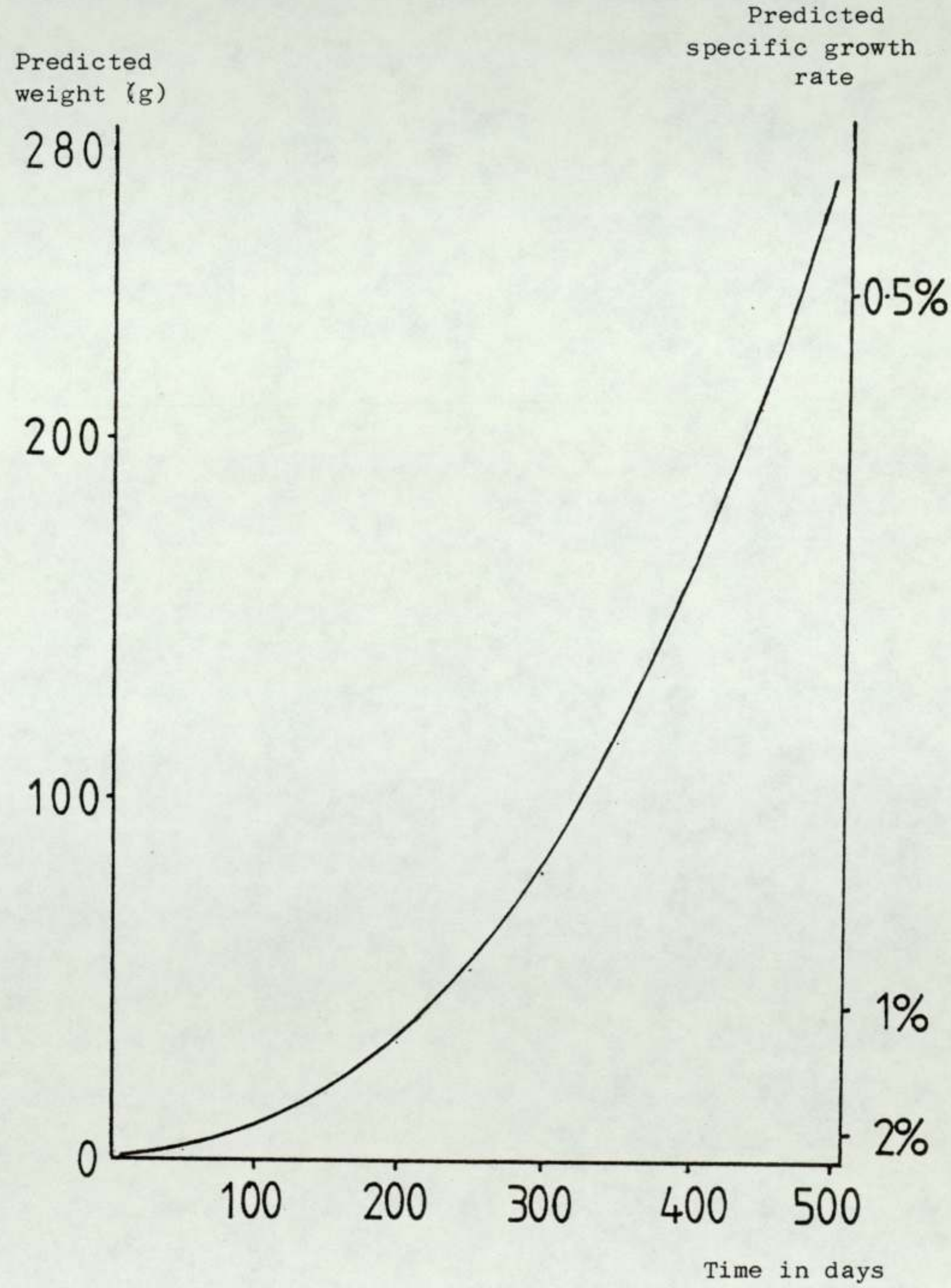
3. Effect of Growth Rate on Time to Harvest

We are now in a position to evaluate the effect of increasing the growth rate on the time it takes to produce portion-sized rainbow trout from a weight of 0.1g at first feeding to 250g at market size, we will be able to compute the value of "a", assuming a value of "b" of -0.4. Given these assumptions and the growth model of Brett and Shelbourn (1975), the growth rate at the start of the growing season will be 11.279 per cent per day, this declining in a logarithmic fashion to 0.497 per cent per day at harvest size (250g). The weight of fish against time is shown in Figure 4 ; the right-hand vertical axis shows the growth rate for a given weight or time. This data is also shown in Table 13.

These results agree well with the growth rates and actual weight found on trout farms in this country, and also with Stauffer (1973), Spurre (1976), Iwama and Tautz (1981), and Whitehead et al. (1980). In this last quoted work, the authors used feeding tables published by a feed manufacturer to estimate weekly weight increases and the time to harvest, given the recommended feeding level, and a typical temperature regime. The model used here takes no account of the influence of temperature, and it is not necessary to do so for, since we are interested in the effect of growth rate, temperature should not be allowed to vary as well. The model does not agree fully with growth rates obtained in experiments conducted in the laboratory, but given differences in the stocking density, stress levels, etc., it is to be expected that growth rates on a farm will be lower than those obtainable in a laboratory.

However, by using different values of "a", it is possible to construct a series of tables which would give the predicted weights of the fish at given intervals. Such tables would be useful to the trout

FIGURE 4 : Predicted weight and growth rate of rainbow trout from zero to 500 days, using the iterative equation and parameters shown in Table 13



farmer since, once he knows the average weight of his fish and the time since first feeding, he can estimate the time it will take for his fish to reach a given harvest size.

It is now possible to increase the growth rate used and evaluate the effect on the time to reach harvest size ; this is shown in Table 14.

TABLE 13 : Predicted weight and specific growth rate of rainbow trout every 30 days, given the assumptions and parameters shown at the bottom of the Table

Day number	Weight (g) at end of day	Specific growth rate (% per day)
1	0.11	11.28
31	0.86	4.85
61	2.65	3.08
91	5.73	2.25
121	10.35	1.78
151	16.68	1.47
181	24.92	1.25
211	35.22	1.09
241	47.73	0.96
271	62.58	0.86
301	79.92	0.78
331	99.86	0.71
361	122.53	0.66
391	148.04	0.61
421	176.50	0.57
451	208.01	0.53
481	242.69	0.50
511	280.62	0.47

According to the iterative equation

$$\text{New Size} = \text{Old Size} \left\{1 + \frac{e^{(a + b\log_e \text{Old Size})}}{100}\right\}^N$$

where N = the number of days between iterations and "a" and "b" are constants dependent upon environmental and genetic factors

where a = 1.50 ; b = -0.4 ; n = 1

A program to calculate these outputs is given in Appendix 5.

TABLE 14 : Effect of increased initial growth rate on the predicted time to harvest of rainbow trout

Initial specific growth rate (as % per day)	Relative initial specific growth rate	Value of a	Time to reach harvest size days (months)	Time to reach harvest size relative to 16 months
11.28	100	1.502	487(16.0)	100
11.84	105	1.551	464(15.2)	95.3
12.41	110	1.597	443(14.6)	91.0
12.97	115	1.642	424(13.9)	87.1
13.53	120	1.684	406(13.3)	83.3
14.10	125	1.725	390(12.8)	80.1
14.66	130	1.764	375(12.3)	77.0
15.27	135	1.802	361(11.9)	74.1
15.79	140	1.838	349(11.5)	71.7
16.35	145	1.873	337(11.1)	69.2
16.92	150	1.907	325(10.7)	66.7

Table 14 shows that, for instance, an increase in growth rate from 11.28 per cent per day to 12.97 per cent per day will decrease the time to harvest from 487 days (16 months) to 424 days (13.9 months). The effect of this increase on the profitability in producing portion-sized rainbow trout needs to be examined.

4. Fixed and feed costs in rainbow trout farming

Feed costs are perhaps the biggest single element in the cost of producing portion-sized rainbow trout. However, another set of costs are fixed costs such as labour, interest on capital, holding facilities, buildings, land etc., the level of which is independent of the growth or feeding level of the fish. These costs usually amount to a large proportion of production costs and will obviously contribute smaller amounts to the cost of producing each fish as growth rate is increased. Thus by increasing growth rates, the importance of these fixed costs is reduced. There is a third group of costs which are variable, non-feed costs. These usually include the purchase of eggs or fry, packaging and transport of the finished product and will vary with output. In the following appraisal of the effect of increasing growth rate on profitability, a set level of expenditure on these costs per unit weight of fish produced will be assumed.

In the most recent and most comprehensive study of the costs of producing rainbow trout, Lewis (1979) found that on average, 47.4 per cent of the costs were fixed costs, 34.6 per cent were on food alone, and that the rest of the costs were due to fish purchases, transport costs and other non-food, variable costs. However, since we are examining costs on farms which grow fish from eggs, we should use costs that apply to these farms. Lewis (1979) also found that of the ten farms either growing from bought-in eggs, or from their own eggs, 45.6 per cent of the costs were due to fixed costs, while 45.4 per cent were due to feed costs. The total costs of producing rainbow trout were 113.3 pence per kg of fish produced.

5. Effect of growth rate on profitability

The costs found to be applicable by Lewis (1979) will be used as relevant to growing portion-sized (250g) rainbow trout from first-feeding fish within 16 months. The effect of increased growth rate on the contribution of fixed costs to the total costs, and so on the profit to the farmer is shown in Table 15.

Initial growth rate	Relative initial growth rate	Time to harvest in days	Feed costs pence per kg of fish produced	Fixed costs pence per kg of fish produced	Gross revenue pence per kg of fish produced	Net revenue per growth cycle in pence per kg of fish produced	Net revenue per per year in pence per kg of fish produced
11.28	100	487	51.4	51.6	121.0	18.0	13.5
11.84	105	464	51.4	49.2	121.0	20.4	16.1
12.41	110	443	51.4	46.9	121.0	22.7	18.7
12.97	115	424	51.4	44.9	121.0	24.7	21.3
13.53	120	406	51.4	43.0	121.0	26.6	23.9
14.10	125	390	51.4	41.3	121.0	28.3	26.5
14.66	130	375	51.4	39.7	121.0	29.9	29.1
15.23	135	361	51.4	38.2	121.0	31.4	31.8
15.79	140	349	51.4	37.0	121.0	32.6	34.1
16.35	145	337	51.4	35.7	121.0	33.9	36.7
16.92	150	325	51.4	34.4	121.0	35.2	39.6

TABLE 15 : Effect of increased initial growth rate upon the profitability of trout farming

The current average wholesale price of whole rainbow trout is around 131 pence per kg, equivalent to 65 pence per lb. (see, for instance, Fish Farmer, 1981, Vol.4, No.5, p.45). If it is assumed that non-food, variable costs amount to 10 pence per kg. (Lewis 1979), the gross revenue will be 121 pence per kg (or 55 pence per lb.) and this figure is shown in the relevant column in Table 15. It has also been assumed that the price will remain constant, irrespective of increases in growth rate and production.

Table 15 shows that by increasing growth rate, the farmer gains on two points : firstly, by reducing the contribution of fixed costs to each unit weight of fish produced, and secondly by growing fish faster so as to be able to produce a greater tonnage of fish in the same time period. These two factors combined have a substantial effect on profit. For instance, an increase in initial growth rate from 11.28 per cent to 13.53 per cent produces an increase in profit from 13.5 pence per kg to 23.9 pence per kg.

The major reason that such impressive increases in profit will accrue from an increase in growth rate is that both feed conversion and feed price are unchanged. This is unlikely since any animal will become more inefficient at laying down flesh as it does so faster, a point well demonstrated by Brett et al. (1969), and of importance in the economics of trout and salmon production (Crampton and Jackson 1981a, 1981b). However, for the moment, it is important to separate an increase in growth rate from its concomitant increase in feed conversion ratio.

It is also possible to examine the effect of decreased feed costs on profit. Such decreased feed costs may be brought about by, for instance, the use of less costly protein sources (see, for instance, Groop et al., 1976; Dabrowski and Wojno, 1977) or by the use of optimum protein to lipid ratios (see, for instance, Lee and Putnam, 1973).

6. Effect of feed costs on profitability

The effect of decreased feed costs upon profitability of trout farming is given in Table 16. The second column in this table is the inverse relative feed costs which increase as the absolute feed costs decrease. This has been used so that a direct comparison may be made with Table 15 showing the effect of increased growth rate on profitability.

A decrease in feed costs from 30 pence per kg. to 25 pence per kg. would increase profit by 48 per cent (from 13.5 pence per kg. to 20 pence per kg.). However, the examination of increased growth rate or decreased feed costs are rather meaningless when taken on their own. Growth rate, feed price and feed conversion ratio are all interdependent and they should be examined in conjunction with each other. The question then becomes : how valuable would it be to achieve, for instance, a 10 per cent increase in growth rate at the "cost" of a 12 per cent increase in feed costs or conversion ratio ? To put it another way, will a diet producing a growth rate, for example, 10 per cent higher and costing, for example, 12 per cent more than a conventional diet result in higher or lower profits to a fish farmer ?

Feed costs (pence per kg)	Inverse relative feed costs	Feed costs in pence per kg of fish produced	Fixed costs in pence per kg of fish produced	Gross revenue in pence per kg of fish produced	Net revenue per growth cycle in pence per kg of fish produced	Net revenue per year in pence per kg of fish produced
30.00	100	51.4	51.6	121.0	18.0	13.5
28.57	105	49.0	51.6	121.0	20.4	15.3
27.27	110	46.7	51.6	121.0	22.7	17.0
26.09	115	44.7	51.6	121.0	24.7	18.5
25.00	120	42.8	51.6	121.0	26.6	20.0
24.00	125	41.1	51.6	121.0	28.3	21.2
23.08	130	39.5	51.6	121.0	29.9	22.4
22.22	135	38.1	51.6	121.0	31.3	23.5
21.43	140	36.7	51.6	121.0	32.7	24.5
20.69	145	35.4	51.6	121.0	34.0	25.5
20.00	150	34.3	51.6	121.0	35.1	26.3

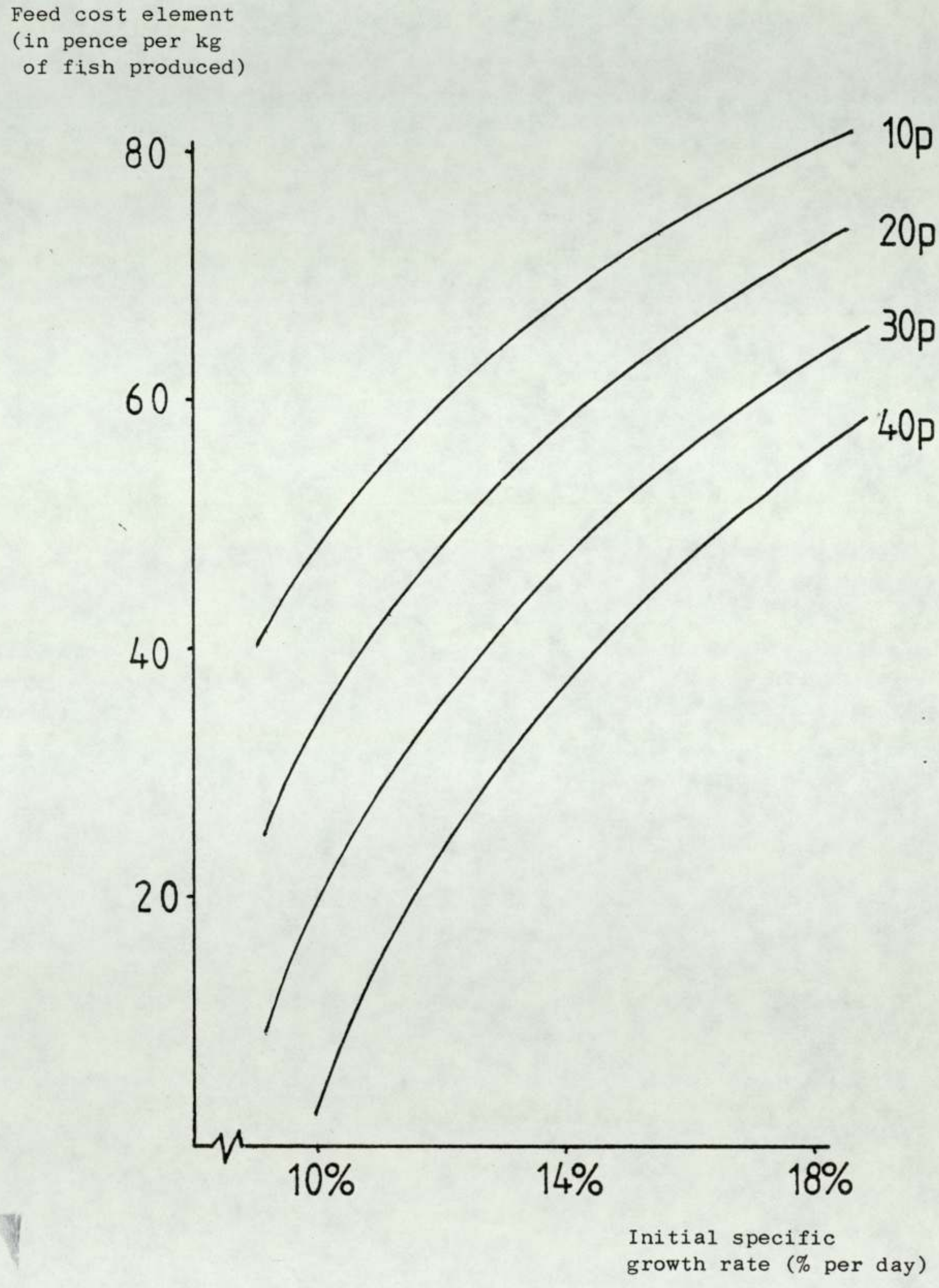
TABLE 16 : Effect of decreased feed costs on the profitability of rainbow trout farming

7. Lines of equal profit

One method that can be employed to examine growth rate and feed costs in conjunction is to find the points at which a farmer will make the same profit for given growth rates and given feed costs. To do this it is first necessary to introduce the term "feed cost element". This is simply the product of the feed costs per tonne and the feed conversion ratio, and is the cost per unit weight of fish that feed alone has contributed. Thus, a feed cost of £350 per tonne and a feed conversion ratio of 1.8 would result in a feed cost element of £630 per tonne of trout produced (350 x 1.8) or 63pence per kg. of trout produced.

Figure 5 gives the profit a farmer will achieve for a range of growth rates and feed cost elements. A price for rainbow trout of 121pence per kg. allowing for non-feed, variable costs has been assumed. It has also been assumed that a fixed cost of 51.6P per kg. of trout produced is typical when the time to harvest is 16 months. Both assumptions are in close agreement with Lewis (1979). This can be used to evaluate competing feeds in terms of the likely return to the farmer. For instance, a feed costing 30pence per kg. and returning a feed conversion ratio of 1.6 would therefore have a feed cost element of 48pence per kg. If it produced an initial specific growth rate of 10 per cent per day, it would give to the farmer a profit of approximately 10pence per kg. of fish produced. An alternative might be to use a feed producing an initial specific growth rate of 13 per cent per day, that costs 35pence per kg. and gives a conversion ratio of 1.6. The feed cost element of this feed would be 56pence per kg. The profit a farmer could expect to make would be 17.61pence per kg. If these assumprions are valid, it would be significantly more profit-

FIGURE 5 : Lines of equal profit in rainbow trout farming (in pence per kg of fish produced per year) given the initial specific growth rate and the feed cost element



able to use a more expensive feed which produces faster growth. Similarly, the figure can be used to compare any set of competing diets once the growth rate, feed conversion ratio and cost of the diet are known.

This figure can also be used to evaluate the optimum feeding level if the farmer wants to maximise profits. As the specific growth rate increases with the increasing feeding level, so the feed conversion ratio also increases, which results in a higher feed cost element. The best compromise between feed cost element and growth rate can be determined.

One of the most noticeable features of the figure is that the lines of equal profit are, in fact, convex curves. This implies that the marginal utility of increasing growth rates decreases; that is, it becomes continually less advantageous to a farmer to increase the growth rate of his trout as the fish attain higher and higher growth rates. This is also noticeable in Table 13, where the increased profit for a given increase in growth rate decreases with the level of growth rate.

This exercise does make some rather gross assumptions, and the validity of the assumptions will vary with the farm concerned. For instance, the fixed costs of growing trout will vary with the type of holding facility and the size of the farm; the average price at which the trout are sold will vary with the size of the farm, and the feed conversion ratio will vary with the type of holding facility. This model also assumes that if a fish farmer grows his fish faster, he will be able to restock his holding facilities quickly with another batch of fish in order to realise the benefit from growing his fish faster. Nor does this model take account of temperature or stocking density. Finally, it has been assumed that the farmer will want to maximise profits, though often he will be more interested in attaining a higher production level or a measure of self-sufficiency.

Nonetheless, the exercise is a useful one; it allows the researcher to evaluate the effectiveness of any improvements in feeds to the probable profits to a farmer. The model will be used for this purpose in later sections of this work.

CHAPTER 8

GROWTH RESPONSES OF TROUT FED SPRAY-COATED DIETS

1. Introduction

The use of fishery wastes as a major ingredient in a diet has been shown in Chapter 6 to be a costly additive in terms of its final value at the site of use. It is possible, however, that some benefit may be gained through increased feed intake by the use of diets which have been spray-coated with a silage made from either whole fish, or from filleting waste. It is known that the palatability of pet feeds are improved by the use of a coating consisting of an animal-based silage (e.g. chicken gut silage). (UK Patent 1,465,267,1977; US Patent 4,089,978,1978; Fazzina, 1978; Kitchell, 1978; Spiegel, 1978, 1979; Walker, 1978). Such a coating will only increase the cost of the diet by a small amount since the low level of silage used (in the region of 5 per cent) will not add significantly to transport costs and no other additives (with the possible exception of potassium sorbate) are usually required. However, the effect upon intake and consequent growth may be significant and, as has been shown in Table 15, only a small increase in growth rate can have a pronounced effect upon profitability.

It has been shown that fish have highly sensitive olfactory organs, especially in response to the amino acids in their aquatic environment (e.g. Suzuki and Tucker, 1971; Sutterlin and Sutterlin, 1971; Hara, 1973; Johnson, 1980), and it is well known that migrating salmonids depend heavily on olfactory cues to return to their original spawning grounds (e.g. Groves et al., 1968; Nordeng, 1971; Hasler et al., 1978; Selset and Døving, 1980; Døving et al., 1980; Johnson and Hasler, 1980). It has also been shown that fish have the ability to distinguish between diets supplemented with animal extracts, amino acids and nucleosides, and that they increase intakes of feeds supplemented with these growth substances (Adron et al., 1973; Mackie, 1973; Carr and Chaney, 1976; Carr et al., 1977; Adron and Mackie, 1978; Mackie and Adron, 1978; Mackie et al., 1980). A silage made from fishery products will contain these feeding stimulants and, since silage is water soluble, it may induce a higher level of feed intake through olfactory stimulation. Secondly, the texture of the pellet will be softened, which may lead to improved palatability to the fish. The effect of these two methods of increasing palatability, intake, and so growth will be studied in this part of this work.

The method chosen for the addition of the fish silage was that of spray-coating, since this would be the most effective in releasing the silage into the water. It is also a method that is easily employed and will be less likely to lead to microbial spoilage of feed. The basal diet chosen was very similar in composition to commercial trout diets.

Three experiments were conducted to examine the effect of spray-coating two types of basal diet with a silage made from filleting waste. This experiment is reported in this chapter.

2. Materials and Methods

a) Diets

The control diets used were dry diets without any coating, and were composed of the ingredients shown in Table 17. The experimental diets were the same diets spray-coated with fish silage made from fish filleting waste minced through a plate with 0.4mm diameter holes and mixed with 3.5 per cent (V/W) 85 per cent formic acid. Such a coating is likely to have an effect on both the texture and smell of the pellet. In order to evaluate the effect of texture alone, two additional groups of fish were fed the basal diets sprayed with water instead of silage.

The two basal diets were fish meal based (Type I) and fish meal plus soya meal based (Type II). The diets were designed to be isonitrogenous and isocalorific on a dry weight basis with soya meal partially replacing fish meal. The proximate analyses of these diets are given in Table 18.

The reason for producing two basic sets of diets is to test for any interaction between the diet type and the coating method. Soya meal may produce a less palatable diet than fish meal and so improvements in palatability through coating should have a more pronounced effect than with a fish meal based diet.

The amount of material sprayed onto the diets amounted to approximately 5 per cent of the dietary weight and was sprayed by use of an ordinary garden spray gun. The fish silage was sieved before spraying to remove fine bone particles.

TABLE 17 : Composition of the two basal diets used in the experiment designed to examine the effect of the spray-coating of of the diets upon the growth rate of rainbow trout

	Type I diet fish meal based	Type II diet soya+fish meal based
Provimi '66[1]	20	5
Soya meal	5	27
Soya oil	4	5
Wheat middlings	22	14
Norseamink[2]	20	20
Special G fishmeal[3]	4	4
Blood meal	4	4
Meat meal	5	5
Dark grains	10	10
Vitamin and mineral mix	2	2
Binder	2	2
Moisture	2	2
TOTAL	100%	100%

[1]Fishmeal made from filleting waste. [2]Fishmeal made from whole fish.
[3]Dried condensed fish solubles.

TABLE 18 : Proximate analyses of the two basal diets in the in the experiment designed to examine the effect of the spray coating of the diets upon the growth rate of of rainbow trout

	Type I diet(%)	Type II diet(%)
Protein	42.0	40.0
Oil	11.7	10.3
Ash	10.4	9.3
Moisture	10.3	11.0
Carbohydrate	25.6	29.4

Protein : Kjeldahl method ; N x 6.25
Oil : Ether extraction
Ash : 24 hours at 450°C
Moisture : 24 hours at 105°C
Carbohydrate : By difference

All analysis conducted by Aynsome Laboratories, Cumbria.

b) Fish

A six-tank recycling system was used to stock a total of 78 rainbow trout (Salmo gairdneri) distributed equally by weight and number and fed twice daily, six times a week to satiation. The fish were weighed every nineteen days, and after each weighing were moved to a different tank to obviate tank differences. The experiment was conducted between November and January at ambient temperatures (7 to $11^{o}C$) over three nineteen-day periods, thus totalling 57 days.

3. Results

The two tanks of fish fed the silage sprayed diets grew faster than the tanks of fish fed either the unsprayed or water sprayed diets. When specific growth rate is used as the index, the silage-sprayed diets produced significantly faster growth (at the 0.05 level) except with Diet D. When the average final weight is used as the index, the silage-sprayed diets produced significantly larger final weights (again at the 0.05 level) except with diet B. These results are shown in Table 19 ; Figure 6 also shows the average weekly weights against time for each of the diets.

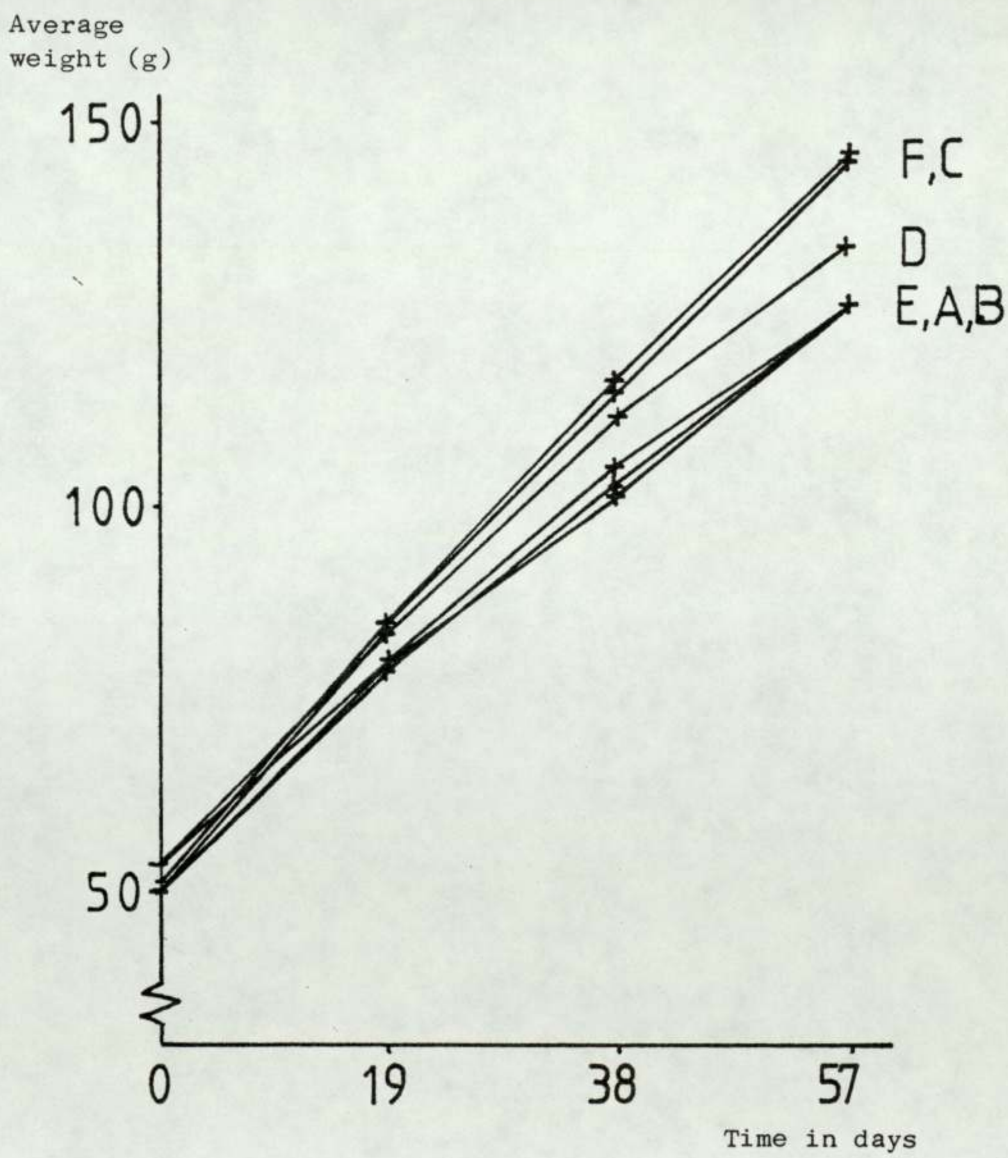
The difference in growth produced by the silage-sprayed diets represents an increase in specific growth rate of approximately 15 per cent.

Surprisingly, the soya plus fish meal diets produced very similar growth rates to the fish meal diets ; it would seem that under these experimental conditions, and at this level of substitution, soya meal

FIGURE 6 : Average weekly weights of rainbow trout fed one of two basal diets, either unsprayed, water-sprayed or silage-sprayed

Key

A	Unsprayed	}	Fish meal based diet
B	Water-sprayed	}	
C	Silage-sprayed	}	
D	Unsprayed	}	Fish meal + soya meal based diet
E	Water-sprayed	}	
F	Silage-sprayed	}	



is a suitable protein source for rainbow trout. This finding is in broad agreement with other work on the replacement of fish meal by soya meal : that is, such a replacement will result in a poorer growth rate which may often be compensated only by amino acid supplementation of the soya bean diets (e.g. Rumsey and Ketola, 1975; Dabrowski and Wojno, 1977). The soya plus fish meal based produced similar growth rates to the fish meal based diet but at the "cost" of poor feed conversion ratios (see Table 20).

TABLE 19 : Growth of fish fed one of two basal diets, either unsprayed, water-sprayed or sprayed with silage

		Diet code	Average initial weight(g) ± S.E.	Average final weight(g) ± S.E.	Average specific growth weight ± S.E.
Fish meal based	Unsprayed	A	52.4^{a} ± 1.64	126.7^{a} ± 4.41	1.557^{a} ± 0.067
	Water-sprayed	B	49.6^{a} ± 1.70	126.6^{a} ± 5.04	1.652^{ab} ± 0.067
	Silage-sprayed	C	51.1^{a} ± 1.50	145.2^{b} ± 5.66	1.840^{b} ± 0.063
Soya + fish meal based	Unsprayed	D	52.2^{a} ± 1.91	133.6^{ab} ± 6.78	1.613^{a} ± 0.069
	Water-sprayed	E	50.0^{a} ± 1.65	126.8^{a} ± 3.70	1.650^{b} ± 0.041
	Silage-sprayed	F	50.2^{a} ± 1.38	145.5^{b} ± 6.45	1.871^{b} ± 0.048

Different superscripts represent significantly different values at the 0.05 level and beyond.

Conversion ratios for each of the diets are shown in Table 20 and apply to the whole of the experimental period. The conversion ratios of the fish fed water-sprayed and silage-sprayed diets are calculated on an unsprayed basis, arriving at a 5 per cent addition of sprayed material.

TABLE 20 : Feed conversion ratios of fish fed one of two basal diets, either unsprayed, water-sprayed or silage-sprayed calculated on an equivalent unsprayed basis

	Unsprayed diet	Water-sprayed diet	Silage-sprayed diet
Fish meal based diet	1.36	1.33	1.40
Fish meal plus soya meal based diet	1.63	1.72	1.52

Despite the fact that the silage-sprayed diet produced significantly better growth rates, the conversion ratios were not consistently poorer than the unsprayed or water-sprayed diets. However, it is noticeable that the fish on the soya plus fish meal based diet converted their feed less efficiently than fish fed the fish meal based diet. This would suggest that either the amino acid profile of soya diet was poorer than fish meal, or that fish were unable to metabolise the amino acids as efficiently.

4. Conclusions

By reference to Figure 5 (shown in Chapter 7 of this report), it is possible to evaluate the effect of a 15 per cent increase in growth rate. Table 13 shows that a 15 per cent increase in growth rate is likely to result in a 58 per cent increase in profitability to a farmer producing portion-sized rainbow trout. However, feed costs will increase because of the use of silage-spraying.

In Chapter 6, it was estimated that the cost of purchase, transport, ensilage and transport of fish filleting waste would be £69 per tonne of silage. At a level of 5 per cent addition, this would add £3.45 to the cost of the ingredients. Hence, to a diet previously with ingredient costs of £272 per tonne, the new cost of the ingredients would be £275.45 per tonne. This would imply a total silage-sprayed diet cost of £324 per tonne (assuming the ingredients contribute 85 per cent of the costs). Transport costs would be 5 per cent higher, adding £0.75 to each tonne. Hence, the extra costs to a farmer of a silage-sprayed diet would be approximately £5 per tonne, or 0.5 pence per kg.

Using Figure 5 in Chapter 7, a farmer growing his fish at an initial specific grwoth rate of 11.5 per cent per day, and having a feed element cost of 56 pence per kilo, would make a profit of 10 pence per kg of trout produced. An increase of 15 per cent in growth rate would imply an initial growth rate of 13.2 per cent. An increase in the price of feed of 0.5 pence per kg (coupled with a feed conversion ratio of 1.7) would increase the feed element cost from 56 to 56.8 pence per kg. These two parameters would give a profit to the farmer of 18 pence per kg of trout produced. An increase in profit of 80 per cent is considerable, and as such, this method of increasing intake deserves further investigation.

One crucial factor in this type of experiment is the judgement of the point at which the fish are satiated. Since this is a subjective assessment, it was decided that in further experiments, feeding would be carried out by technical staff so as to eliminate any possibility of feeding bias by the author.

CHAPTER 9

COMPARATIVE EFFECT OF ATTRACTANT SPRAYING AND ATTRACTANT INCLUSION UPON GROWTH RATE

1. Introduction

It is possible that the growth differences due to silage spraying reported in the previous experiment were due to an unconscious bias in feeding. For this reason, and because of the possible commercial importance of these findings, two further experiments were conducted in which feeding was carried out by technical staff so as to minimise the possibility of bias. The first of these experiments was conducted at Aston, and was designed to test both the effectiveness of spraying as a method of increasing palatability, and also the possibility of using silage as an attractant when included as part of the ingredients prior to pelletisation. This is because one of the problems of spraying is that it produces a sticky pellet which is unpleasant to handle and which is likely to be difficult to use in automatic feeders. The inclusion of silage in the ingredients may have the same positive effect on palatability, but must overcome this handling problem if it is to become commercial. The second parallel experiment, conducted at Sudbury, is reported in Chapter 10.

2. Materials and Methods

a) Diets

Six diets were made at Sudbury and consisted predominantly of remixed No. 1 trout pellet. Diets A, B and C contained attractants added prior to pelletisation. The attractants for diets D, E and F were sprayed onto the pellet after pelletisation. The composition of diets A, B and C are given in Table 21.

TABLE 21 : Composition of diets with an attractant incorporated in the pellet as a dietary ingredient

Ingredient	Diet A	Diet B	Diet C
No. 1 trout pellet	87%	87%	87%
Dried distillers solubles	5%	5%	5%
Wheat midds	2.5%	-	-
Water	5.5%	-	-
Chicken silage	-	8%	-
Fish silage	-	-	8%
TOTAL	100%	100%	100%

These diets will produce very similar proximate compositions due to the high water content of the variable materials. The only aspect that may change is the palatability of the diet.

Diet A was designed to act as a control since water is not expected to have any attractant effect. Both chicken silage and fish silage will be water soluble, and consequently, may be effective in acting as an attractant. Diets D, E and F were produced by spraying diet A with water, chicken silage and fish silage respectively. Since water spraying does not seem to have any effect upon palatability, diet D may be seen as a second control. Diets E and F may be compared with diets B and C respectively since the attractant added is the same;

the only aspect that varies is the method of addition.

The fish silage consisted of fish filleting waste stabilised with the addition of formic acid. The chicken silage consisted of poultry gutting waste stabilised with the addition of propionic and citric acids.

b) Fish

Two, three-tank recycling systems were used and stocked with a total of 78 rainbow trout distributed equally by weight and number and fed twice daily on weekdays and once daily at week-ends, to satiation by technical staff.

The fish were weighed individually at the start and end of the experiment, which lasted 9 weeks; the fish were moved to a new tank every 10 or 11 days so that each group of fish spent the same number of feeding days in each tank. The experiment was conducted between May and July at ambient temperatures of 12 to 17^{o}C. One mortality occurred on Diet D.

3. Results

With the exception of diet C, there were no significant differences in either specific growth rate or final weight between groups of fish (see Table 22). Mean fish weights on each diet are shown for each weighing day in Figure 7. The number of cases is 13 for all diets except diet D where it is 12.

TABLE 22 : Growth indices of rainbow trout after feeding for 63 days on diets in which the attractant was either sprayed onto the diet or included as an ingredient

Diet	Average initial weight(g) ± S.E	Average final weight(g) ± S.E	Mean specific growth rate ± S.E
A	78.5^{a} ± 2.87	217.6^{b} ± 10.60	1.62^{b} ± 0.047
B	77.9^{a} ± 2.52	203.4^{ab} ± 10.14	1.52^{b} ± 0.069
C	77.2^{a} ± 2.34	181.8^{a} ± 8.40	1.35^{a} ± 0.055
D	77.1^{a} ± 2.19	209.1^{b} ± 11.29	1.58^{b} ± 0.069
E	77.9^{a} ± 2.82	202.9^{ab} ± 13.64	1.49^{ab} ± 0.100
F	78.7^{a} ± 2.46	205.6^{ab} ± 10.67	1.52^{b} ± 0.075

Different superscripts represent significantly different values at the p = 0.05 level.

Diet C is the one in which fish silage was added prior to pelletisation, and the difference in growth may be due to the use of formic acid. However, the depression in growth is out of proportion to the amount of formic acid used and furthermore, such differences are not present in the growth response on diet F, nor on any of the sprayed diets reported in the previous experiment. It is thus surprising that diet C does produce this difference in growth.

No other diets produced significantly different results as far as mean final weights or specific growth rate were concerned. The largest difference in specific growth rate (excluding the result of diet C on the grounds that it is spurious) is between diet E and diet A, but even here the difference is only around 9 per cent, rather small considering the nature of the feeding method and the difference obtained in the previous experiment. Furthermore, the difference is in favour of the control diet. Nor do average feeding rates or feed conversion ratios differ with the diet, as shown in Table 23.

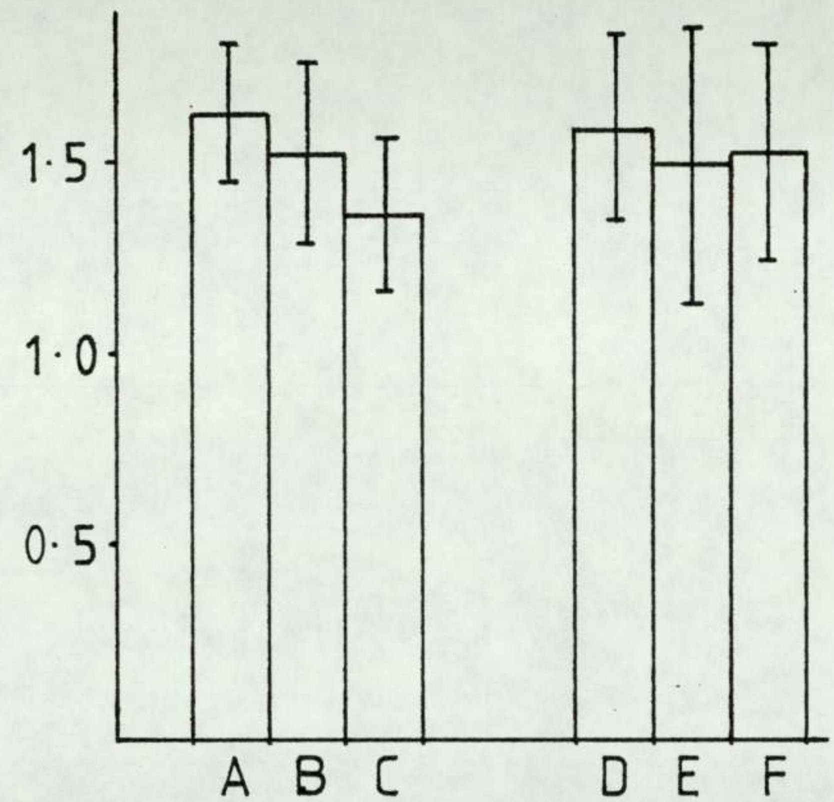
TABLE 23 : Feeding rate and feed conversion ratio of rainbow trout after feeding for 63 days on diets in which the attractant was either sprayed onto the diet or included as an ingredient

	A	B	C	D*	E	F
Feeding rate (% body wt. per day)	2.19	2.16	2.12	2.10	2.16	2.13
Feed conversion ratio	1.35	1.42	1.57	1.33	1.45	1.40

* One mortality occurred in the last week on diet D. Intake has, therefore, been computed on the basis of 12/13 of the total intake.

The most striking feature of these results is that the feeding rates are remarkably similar, differing only at the second decimal place. Feed conversion ratios thus largely reflect the differences in growth rate. What this implies is that activity responses of feeding are very similar for all diets. This was also reported by the technical staff carrying out feeding. It seems, therefore, that no difference in intake or growth occur with the inclusion of either a mixed or sprayed, acid-based, water-soluble attractant.

FIGURE 7 : Mean specific growth rates of rainbow trout after feeding for 63 days on diets in which the attractant was either sprayed onto the diets (diets A, B and C) or included as an ingredient (diets D, E and F)



Key

A water
B chicken silage
C fish silage } Added in

D water
E chicken silage
F fish silage } Sprayed on

It might be expected that the addition of a sprayed coating to diets D, E and F might produce similar growth rates to diets A, B and C, but slightly poorer conversion ratios. The fact that this is not the case may be due to a level of overfeeding which has ensured maximum intake, but masked any difference due to the coating level.

4. Discussion

These results do not confirm those obtained in the previous experiment. This may be due to greater care over feeding to satiation in the previous experiment, unconscious bias in feeding, or lower water temperatures. Whatever the case, these results must cast serious doubts on the use of this method of increasing the palatability of commercial trout diets. In view of the fact that this experiment did not confirm the result of the previous experiment, a further experiment was conducted to further examine the effect of spray coating.

CHAPTER 10

COMPARISON OF UNSPRAYED AND SILAGE-SPRAYED DIETS

1. Introduction

The third experiment designed to evaluate the use of silage as a water soluble attractant sprayed onto the diet is reported in this chapter. It was carried out at Sudbury by a member of staff.

2. Materials and Methods

a) Diets

The diet used was No. 1 trout diet mixed and repelletised using an addition of 5 per cent dried distillers' solubles so as to produce a commercial-type trout diet from the same production batch. The control diet was left unsprayed. The experimental diet was a silage-sprayed version of the control diet. The silage was made from fish filleting wastes stabilised with a 3 per cent addition of formic acid. Spraying increased weight by around 15 per cent.

b) Fish

Twenty-one rainbow trout, initial weight 100g, were used to stock two tanks (ten on the control diet, eleven on the experimental one) and fed to satiation twice daily on weekdays and once daily at week-ends. The experiment lasted for eight weeks. The fish were weighed at the start and end of the experiment, and midway through the experiment.

Every two weeks, the fish and their respective diets were changed between tanks to remove tank differences.

3. Results

No differences were apparent after eight weeks of feeding, in either mean final weight or in mean specific growth rate. Growth indices over the eight week experiment are shown in Table 24. Different superscripts represent significantly different results at the .05 level, using students' t-test.

TABLE 24 : Growth indices of fish fed over a period of eight weeks either an unsprayed or silage-sprayed diet

Diet	Initial weight(g) ± S.E	Final weight(g) ± S.E	Mean specific growth rate ± S.E
Control (unsprayed)	103.3[a] ± 4.17	222.3[a] ± 8.79	1.38[a] ± 0.06
Experimental (fish silage sprayed)	96.5[a] ± 9.14	206.8[a] ± 17.34	1.38[a] ± 0.03

Different superscripts represent significantly different results at the 0.05 level.

Conversion ratios and daily feeding rates are different, as can be seen from Table 25. Feeding rates and conversion ratios are approximately 15 per cent higher for the sprayed diets and this reflects the difference in the amount of material sprayed.

TABLE 25 : Feeding rate and feed conversion ratios of fish fed over a period of eight weeks, either an unsprayed or a silage-sprayed diet

Diet	Mean daily feeding rates	Mean feed conversion ratio
Control (unsprayed)	1.75%	1.37
Experimental (fish silage sprayed)	2.18%	1.58

4. Conclusions

The conclusion from this experiment is that there is no advantage to be gained from the use of spray-coated pellets using what is presumed to be a water soluble attractant. This is in agreement with the experiment reported in Chapter 8. It casts further doubt on the usefulness of this method of increasing palatability of commercial trout diets. The reason for these discrepancies will be discussed in the following chapter.

CHAPTER 11

EFFECT OF SPRAY-COATING ON DIETARY PREFERENCES

1. Introduction

Other workers have shown that fish, like other animals, have the ability to perform simple tasks to gain a reward, such as a supply of food (e.g. Rozin and Mayer, 1961, 1964; Landless, 1976). It has also been shown that rainbow trout can distinguish between feeders stocked with different types of feed (Adron et al., 1973; Adron and Mackie, 1978). It was decided to use this ability to test the effectiveness of spray-coating as a method of increasing the palatibility of diets for rainbow trout.

This was achieved by placing two triggers and feeders in each tank and stocking with different types of feed. Measurement of the number of actuations of each trigger will give an indication of which feed the fish prefer.

2. Materials and Methods

a) Diets

Two sets of diets were mixed at Sudbury, using the same composition as shown in Table 17. Before use, these diets were sprayed with fish silage, water or fish oil, or left unsprayed.

b) Fish

Forty-two rainbow trout (mean initial weight 37g) were individually tagged and divided into three lots and used to stock three experimental tanks. Six demand feeders were designed and built; the design is shown in Appendix 6. Two pairs of feeders/triggers were placed on each tank and stocked with different types of feed. The number of actuations was recorded daily.

The trout were conditioned to the system for three weeks before the start of the experiment. Three sets of comparisons were made in each of the three experiments (A, B and C), and the experiment was conducted for 28 days. Midway through the experiment (i.e. after 14 days) the feeds were changed between feeders to remove differences due to feeder siting. The amount of feed consumed was measured before changing the feeds placed in each feeder.

Analysis of trigger actuations is based on the daily differences in actuations between the diet tested and the control diet. The number of actuations of the control diet was subtracted from the number of actuations of the experimental diet. This gave 28 positive or negative figures; the mean and standard deviations of these were computed, and using student's t-test, were analysed to assess whether the mean was significantly different from zero. Obviously, a positive mean significantly different from zero shows the experimental diet to be preferred. A number not significantly different from zero showed no preference and a negative number significantly different from zero showed a preference for the control diet.

3. Results

Experiment A

Experimental diets were water, fish oil and fish silage-sprayed versions of the fish meal based diets. The control diet was the unsprayed fish meal diet. This was to test the effectiveness of increasing palatability with various types of sprays.

TABLE 26 : Significance of the difference in the number of actuations in tanks where the fish were offered an unsprayed fish meal based diet, and either a water-sprayed, oil-sprayed or silage-sprayed fish meal based diet

Tank	Experimental diet	Control diet	Mean of daily differences	Standard Deviation	Significance level (of mean from zero)
1	Water-sprayed fish meal base	Unsprayed fish meal based	22.71	22.05	0.01
2	Oil sprayed fish meal based	Unsprayed fish meal based	-9.27	11.19	0.01
3	Silage sprayed fish meal based	Unsprayed fish meal based	-0.29	23.62	N.S.

TABLE 27 : Level of intake in tanks where the fish were offered an unsprayed fish meal based diet and either a water-sprayed oil-sprayed or silage-sprayed fish meal based diet

Tank	Experimental diet		Control diet	
	Feed consumed	Average delivery per actuation(g)	Feed consumed	Average delivery per actuation(g)
1	1,310	1.2	562	1.2
2	413	1.2	691	1.2
3	478	0.8	781	1.4

No significant difference in the number of actuations was found to exist with silage spraying, although the amount of the control diet consumed was higher. A positive significance was found to exist for the water-sprayed diet and a negative significance for the oil-sprayed diet.

Experiment B

The experimental diets were the water-sprayed, unsprayed, and silage sprayed versions of the fish meal based diet. The control diets were the same type of spray used on the soya plus fish meal based diets. This was designed to test the comparative palatability of soya and fish meal.

TABLE 28 : Significance of the difference in the number of actuations in tanks where the fish were offered a soya plus fish meal based diet and a fish meal based diet

Tank	Experimental diet	Control diet	Mean of daily differences	Standard deviation	Significance level
1	Fish meal based silage-sprayed	Soya plus fish meal based silage sprayed	-5.39	22.60	N.S.
2	Fish meal based water sprayed	Soya plus fish meal based water sprayed	8.32	37.76	N.S.
3	Fish meal based unsprayed	Soya plus fish meal based unsprayed	6.46	47.49	N.S.

TABLE 29 : Level of intake in tanks where the fish were offered a soya plus fish meal based diet and a fish meal based diet

Tank	Experimental diet Feed consumed (g)	Experimental diet Average delivery per actuation(g)	Control diet Feed consumed (g)	Control diet Average delivery per actuation(g)
1	1,094	1.1	1,737	1.5
2	479	0.7	583	1.3
3	791	0.9	717	1.0

No significant differences were found to exist in the number of actuations for any of the above three comparisons. However, in tank 1, the amount of the control diet consumed was considerably higher than the amount of experimental diet consumed.

It can be seen that the average delivery per actuation often varies between tanks, and for this reason, the number of actuations and the amount of feed consumed should not be examined in isolation.

Experiment C

In all three cases, the experimental diet was the silage-sprayed version of the fish meal diet. And in all three cases, the control diet was the unsprayed version of the fish meal diet.

TABLE 30 : Significance of the difference in the number of actuations in tanks where the fish were offered an unsprayed fish meal based diet and a silage-sprayed fish meal based diet

Tank	Experimental diet	Control diet	Mean of daily differences	Standard deviations	Significance level
1	Silage-sprayed fish meal based	Unsprayed fish meal based	40.93	38.47	0.01
2	Silage-sprayed fish meal based	Unsprayed fish meal based	-1.68	50.22	N.S.
3	Silage-sprayed fish meal based	Unsprayed fish meal based	3.11	46.87	N.S.

TABLE 31 : Level of intake in tanks where fish were offered an unsprayed fish meal based diet and a silage-sprayed fish meal based diet

	Experimental diet		Control diet	
Tank	Feed consumed(g)	Average delivery per actuation(g)	Feed consumed(g)	Average delivery per actuation
1	1,717	1.0	1,042	1.5
2	531	0.9	818	1.3
3	1,025	1.4	867	1.3

It can be seen that a significant difference exists in the number of actuations for only one of the pairs of diets tested here. The results for the levels of intake are largely in agreement with these.

4. Discussion

This series of experiments are a little ambiguous, but one set of results need no clarification. These are the results relating to Experiment B, testing the difference between soya and fish meal. There seems to be no adverse effect upon palatability of the inclusion of soya in fish diets up to the levels investigated here. Perhaps only by including soya at higher levels would it affect palatability, though the level tested here is, in fact, well beyond that which commercial fish meal would usually contain. It will be remembered that the soya diets showed an increase in food conversion ratio in comparison to the fish meal diets, and the result found here would confirm the hypothesis that either digestibility of soya diet or its amino acid profile is poorer than that of fish meal.

The question of silage-spraying is more difficult to resolve, especially in relation to the experiment reported in Chapter 8. In only one of the four comparisons did silage spraying produce a significantly higher number of actuations. This comparison was Experiment C, Tank 1. Why one tank out of four should show a positive result while the others showed no difference may be realised when we take a closer look at the dynamics of preference testing through demand feeders.

It is known that there is a pronounced hierarchy in trout populations (e.g. Landless, 1976). Most of the trigger actuations are usually carried out by one dominant fish. The stimulus to press one trigger in favour of another is most likely to be communicated to the dominant fish by the feeding response of the other fish in the tank. A feeding response that is seen by the dominant fish to be greater for one feed/trigger is likely to produce a higher number of actuations of that trigger. Hence, the greater number of actuations for more palatable feed. This learning process will need to start again when the feeds are swapped between feeders midway through an experiment. The whole process may be illustrated by the following diagram :

General preference for Type A feed by trout population → Higher consumption of Type A feed when trigger A is pressed

↓

Learning by dominant trout that
a) different feeds are dispensed by different triggers
b) One feed (Type A) is preferred

↓

Dominant trout presses Type A trigger more frequently.

This causal path is quite involved, and a point at which it will break down easily is likely to be the perception by the dominant fish of a general feed preference. Such a preference is subjective and it is for this reason that the significance of counter readings are likely to vary from tank to tank. This will be particularly marked if, as seems to be the case, the feed preferences involved here are weak. Work carried out by other researchers in this field (Adron et al., 1975; Adron and Mackie, 1978) shows a marked preference perhaps due to the fact that the control diets were based on casein, a rather unpalatable protein source. The use of additives in commercial fish feed is less likely to have such a marked increase in palatability. It seems that the highly sensitive olfactory senses of the fish means that just a low level of olfactory stimulus is needed to induce feeding. Further increases beyond this point do not produce corresponding increases in intake.

Nonetheless, the oil-sprayed and water-sprayed diets as tested in Experiment A would indicate that a preference exists in this case. It would require further investigation to establish whether this preference is generalised throughout different groups of trout, or particularly this one. However, it is noticeable that the differences in intake between the preferred diet and the non-preferred diet is lower in these experiments than one would expect in the casein-based diets.

Evidence which would suggest that olfactory stimulation is of limited importance to Atlantic salmon in the competition for food is provided by Stabell and Refstie (1980). In this quoted work, the authors cauterised the olfactory mucosa of one group and found no difference in growth between this group and an untreated control group. The authors concluded that vision is of prime importance in feeding. However, since the control and cauterised fish were raised in the same cage, it is possible that the initial stimulus to feed may have been provided for the cauterised fish by the control fish. An experiment in which the two groups were completely separated might have produced a different result.

It is likely that olfaction plays an important part in the arousal of fish to feed since, in most species, fish in which olfactory sense had been eliminated showed an impaired, or absence of, arousal upon presentation of feed (e.g. Bardach and Villars, 1974).

It is probable that olfaction plays an important part in the arousal of rainbow trout to feed, but that the mechanism which dictates when to cease feeding is linked with the energy content of diet and the blood glucose levels in the fish (e.g. Lee and Putnam, 1973; Grove <u>et al.</u>, 1978; Cowey and Sargent, 1979)

However, it is possible that in certain species other than rainbow trout, the "switch off" mechanism is linked to preference for various diets presented. This has been observed, for instance, by Olla et al. (1970) and Nakamura (1962) for bluefish (Pomatomus saltatrix) and skipjack tuna (Euthynnus pelamis) respectively. It has also been widely reported in Norway by salmon farmers, that the satiation level and growth rate of Atlantic salmon is significantly higher when fed diets consisting wholly or partly of frozen whole fish than when fed dry, commercial diets (Edwards, 1977; Edwards, 1979; Crampton and Oakley, 1981).

5. Conclusions

It is likely that the dry feeds currently in commercial use are able to elicit the full arousal of rainbow trout to feed. In other words, no further stimulation to feed will result from a further increase in olfactory qualities of the pellet.

It is also probable that the mechanism which dictates when this species of fish should cease feeding is linked to the blood glucose levels in the fish. Hence, any increase in palatability seems unlikely to increase feeding through this mechanism.

PART 3

THE USE OF FISHERY WASTES IN MOIST DIETS FOR ATLANTIC SALMON

CONTENTS

INTRODUCTION TO PART 3

Rainbow trout do not display increased levels of intake or growth when fed higher palatability diets ; this is the main conclusion from the work of Part 2. However, it is possible that intake in other fish species is limited by the palatability of dry fish feeds currently commercially available. There are also fish species which, because of their higher market value, will be able to tolerate increased feed prices while returning an increased profit to the farmer. For these two reasons, one physiological and one economic, it is possible that other farmed fish species may be more suited to the feeding of a diet containing fishery wastes.

It is for these two reasons that the use of moist diets on salmon farms in Norway is widespread, and fish farmers there report that growth rates on such diets are higher than those obtained with dry diets (see, for instance, Edwards, 1979; Crampton and Oakley, 1981). The use of moist diets is based on the fact that they produce faster growth; their disadvantages are that they are more difficult to use and to feed, more costly to the farmer, less reliable in supply and have a higher pollution and disease risk. The growth differences are commonly ascribed to the higher palatability of moist diets. In this part, the potential of moist diets in Scotland for Atlantic salmon will be analysed. This will consist of an economic appraisal of salmon diets, experimental work to investigate growth differences and the supply and costing of industrial/waste fish.

CHAPTER 12

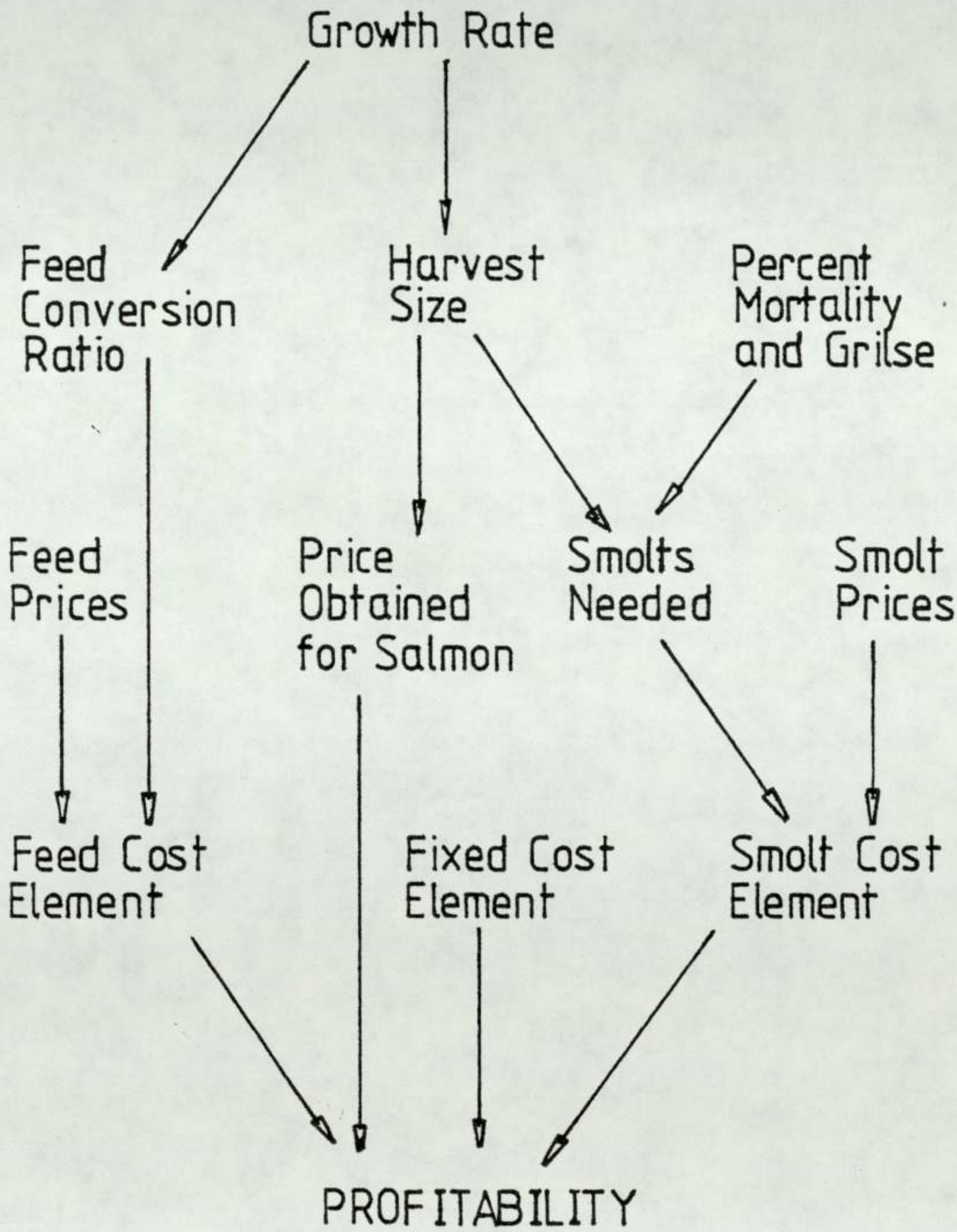
EVALUATION OF ALTERNATIVE STRATEGIES FOR THE IMPROVEMENT OF ATLANTIC SALMON FEED

1. Introduction

It is important to a farmer's profitability that a proper compromise is reached between a high cost diet producing high growth rates and a low cost diet producing poorer growth rates. The point of maximum profit between the two extremes of diet quality will be approximately the same for farmers cultivating the same fish species and using similar methods of rearing, and so it is possible to make quite wide-ranging generalisations regarding strategy once this is understood. In this chapter, the costs and returns applicable to the cage-rearing of Atlantic salmon from smolt size to harvest size will be examined. It will then be possible to judge the best compromise between high growth rates and low feed costs.

The following causal diagram shows the interaction of some of the factors influencing profitability."Feed Cost Element" are the costs per kg. of salmon that feed alone contributes. It is the product of feed costs and feed conversion ratio. Similarly, the "smolt cost element" is the cost per kg that the cost of smolts alone contributes, and is a function of individual smolt costs, per cent mortality and grilse, and the size of harvest. The fixed cost element describes the amount that annual fixed costs contribute to the cost of each kg. of harvested salmon.

FIGURE 8 : A summary of the factors influencing the profitability the profitability of salmon farming



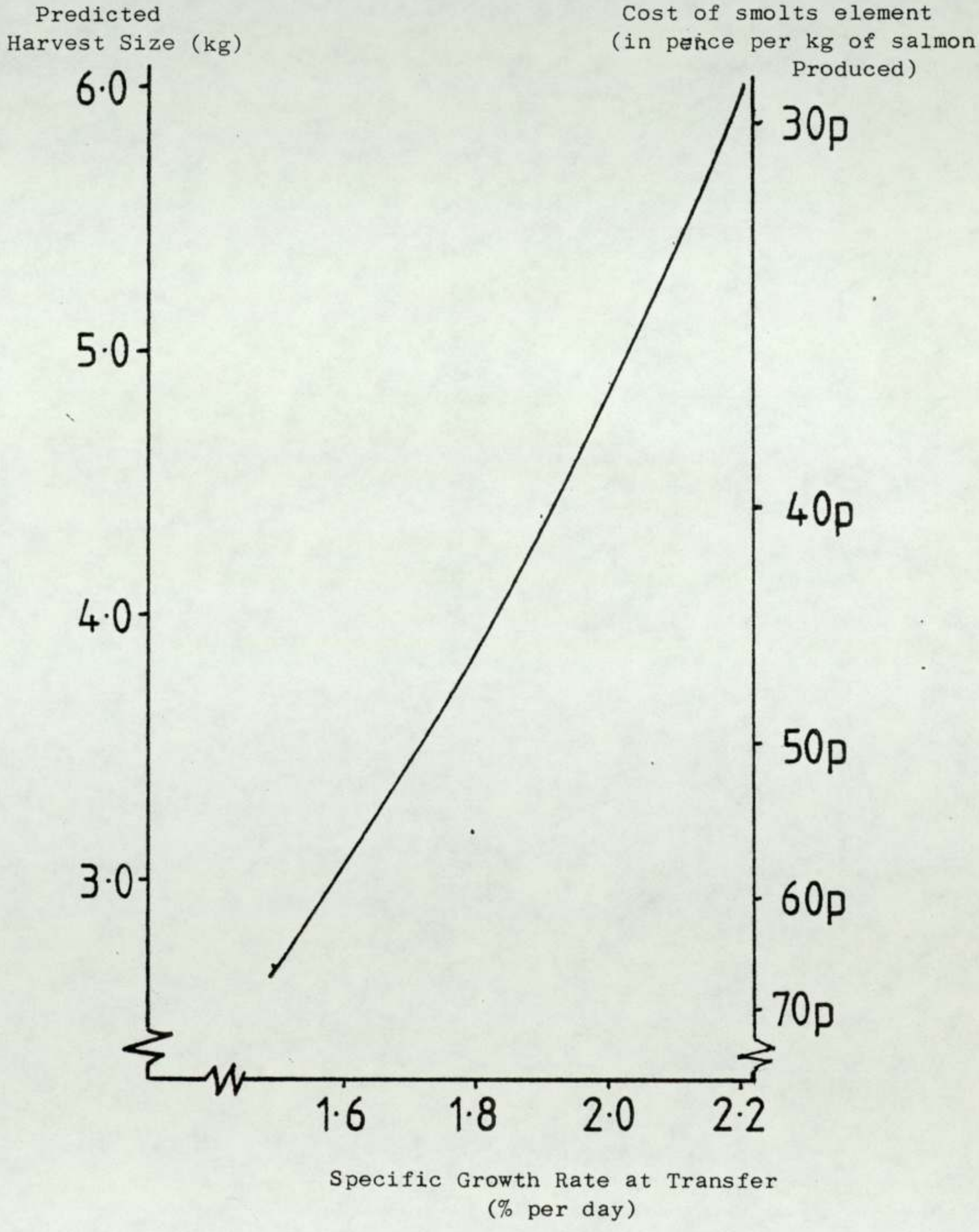
2. Effect of increased growth rate on profitability

Growth rate, feed costs and conversion ratios are the most important factors upon which a diet must be judged. Previous work (Crampton and Jackson, 1981b) has shown that the optimum feeding strategy is to aim for high growth rates and large harvest sizes by feeding to satiation, and to accept the resulting poor feed conversion and high feed cost element. A similar approach will be used to analyse optimum diet design.

In the following analysis, the model outlined in Chapter 7, pages 55-56, will be used to predict harvest size. This model allows for a decreasing growth rate with increasing fish weight.

Figure 9 shows the harvest sizes a farmer may expect if he were to attain various average growth rates. This assumes a smolt size of 40g, and a two-year cycle of growth. The right hand vertical axis shows the "smolt cost element" that a farmer will have to pay, assuming a smolt price of £1 each, and a mortality and grilse level of 43 per cent. A mortality and grilse level of 43 per cent (i.e. a survival to salmon of 57 per cent) is equivalent to a mortality level of 1 per cent per month, plus a grilse level of 25 per cent, levels that are typical on salmon farms in Scotland (Crofter Seafoods Ltd.; Highland Fish Farmers Ltd.). For a more detailed account of the effect of mortality and grilse levels upon profitability, see Crampton and Jackson (1981c). The figures given on the right hand side are the cost per kg of salmon contributed by smolt costs alone. The figure shows how increasing growth rates leads to increasing harvest size and to a reduction in the smolt cost element.

FIGURE 9 : Predicted harvest size of Atlantic salmon and the cost of smolts element in the farming of Atlantic salmon from a given growth rate at transfer, and assuming a 40g smolt, a growth cycle of two years, a survival to salmon of 57% of the smolts, and a smolt price of £1 per smolt



The phrase "at transfer" describes the time when salmon are transferred from their freshwater environment to a sea-water environment. The effect of growth rate on profitability is also determined by the prices obtained at harvest. Table 32 shows a typical price schedule obtainable for salmon at the time of writing (Highland Fish Farmers, Loch Carron, Aberdeen Smoked Salmon Co. Ltd., Aberdeen).

TABLE 32 : Average Atlantic salmon prices, ungutted, on the farm

Size of fish (kg)	Price per kg.
Up to 2.0	£2.00
" " 2.5	£2.50
" " 3.5	£3.50
" " 4.5	£4.50
" " 5.5	£5.50
Over 5.5	£5.50

It is noticeable how the prices increase steadily for the inreasing size of fish. The prices are for whole salmon, on ice, at the farm. Thus, there is a relationship between growth rate and harvest size, and between harvest size and market price. Therefore, it is possible to link growth rate to market price, and so calculate the revenue to a farmer if he were to obtain various growth rates and sell his fish as shown in Table 32. Furthermore, by using the cost of smolts element already calculated, and assuming an annual fixed cost in growing salmon, we can calculate his gross revenue less the smolt and fixed costs elements. These calculations are shown in Table 33.

TABLE 33 : Effect of increasing the growth rate of Atlantic salmon at transfer upon the profitability of salmon farming

Specific growth rate at transfer (% per day)	Harvest size (kg)	Gross revenue per kg (market price) (£) *	Smolt ** cost element (per kg of salmon produced) (pence)	Fixed costs *** element (per kg of salmon produced) (pence)	Gross (£) revenue less smolt and fixed costs element (per kg of salmon produced)
1.6	3.05	3.05	58	75	1.72
1.7	3.46	3.46	51	75	2.20
1.8	3.90	3.90	45	75	2.70
1.9	4.37	4.37	40	75	3.22
2.0	4.87	4.87	36	75	3.76
2.1	5.41	5.41	32	75	4.34
2.2	5.98	5.50	29	75	4.46

* Assuming a price schedule given in Table 32

** Assuming an individual smolt cost of £1 and a survival to salmon of 57 per cent

*** Assuming fixed costs to be £750 per tonne of salmon produced.

The amount shown in the final column is the gross revenue to a farmer, less the smolt and fixed costs elements. In other words, once he allows for the feed cost element, the final column will show the net revenue per kg of salmon produced. We are now in a position to draw a graph showing growth rate on one axis and feed-element costs on the other, and obtain lines of equal profit.

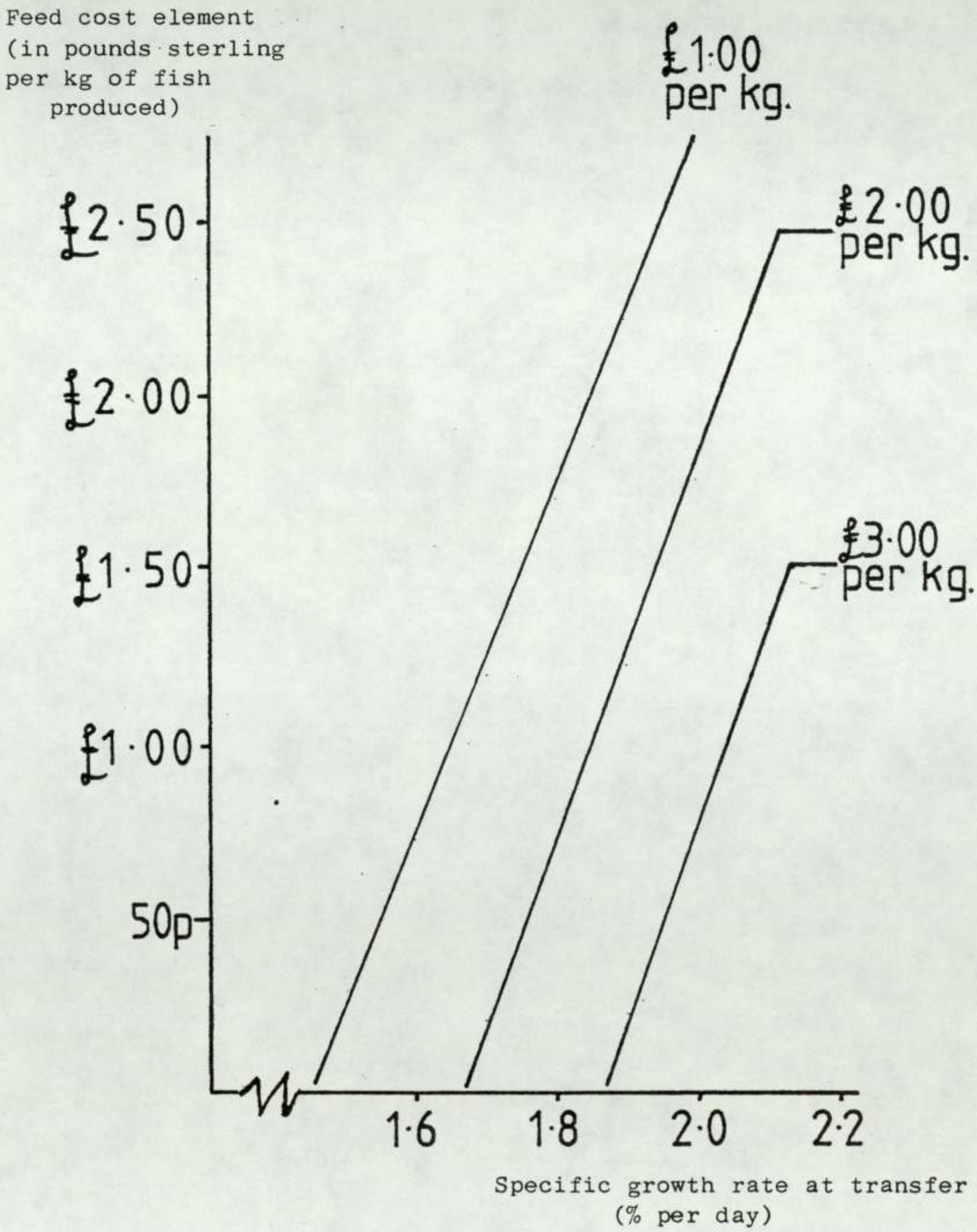
3. Lines of equal profit

Figure 10 is such a graph, using the same assumptions outlined above. Thus, a farmer whose fish grow, at transfer, at a specific growth rate of 1.7 per cent, and have a feed cost element of 2.82 will return a profit of around £1.00 per kg per annum. If the farmer were able to increase the growth rate of his fish to 1.9 per cent at transfer (and maintain a higher growth rate throughout the growth cycle) he would increase his profit to around £2.00 per kg. It is obvious that a small increase in growth rate can have a large effect upon the profitability of salmon farming. By contrast, a much larger increase in feed conversion is necessary to effect profitability to the same extent. If growth rate (at transfer) is allowed to remain constant at 1.9 per cent, an increase in feed cost element from £1.22 to £1.72 would only decrease profitability from £2.00 per kg per annum to £1.50 per kg per annum.

Any combination of growth rate and feed cost element within the limits shown may be compared. It is clear that an increase in growth rate has a much larger effect upon profitability than an equivalent decrease in feed cost element.

The exercise does make some rather gross assumptions, not least the assumption that mortality and grilse will be the same for all competing diets, and that stocking density has no interactive effect with growth rate. However, these assumptions apply to all diets under comparison. The level of parameters chosen (e.g. pricing schedule or mortality and grilse levels) can be altered for each farm, or as the situation changes. This model will be used later for a comparison of diets. However, for the moment, it illustrates the principle that since salmon are a high-valued fish, the optimum strategy in diet design is to secure high growth even at the expense of a high feed cost element.

FIGURE 10 : Lines of equal profit (in pounds sterling per kg of salmon produced) in Atlantic salmon farming, given the growth rate at transfer and the feed cost element during the growth cycle



CHAPTER 13

REVIEW OF LITERATURE UPON THE POTENTIAL OF MOIST DIETS IN SALMON FARMING

In the previous chapter, a small increase in growth rate has been shown to have a greater effect upon profit to a salmon farmer than a similar reduction in feed costs or feed conversion ratio. It is for this reason that I believe it is important to identify ways of improving growth rates and to regard feed costs of secondary importance. It is now possible to review more closely the likely growth advantages with moist feeds. Generally, the evidence is equivocal. Thus, Rungruangsak and Utne (1981) found that once accustomed to a diet consisting of 60 per cent frozen fish (coalfish and capelin) and 40 per cent silage (coalfish and capelin) rainbow trout grew at similar rates to control fish fed on 100 per cent frozen fish (coalfish and capelin), whereas Austreng (1980) found that a diet containing 40 per cent dry components and 60 per cent fish silage (made using formic acid to stabilise a mixture of industrial fish) produced higher growth rates when fed to Atlantic salmon than a diet containing 40 per cent dry components, 60 per cent frozen industrial fish. Other acids used to stabilise the silage produced, for the most part, lower growth rates. When fed to rainbow trout, all these diets produced similar growth rates.

There are no comparisons between dry and silage based diets for salmon. However, Bromley and Smart (1981), working on rainbow trout, found no difference in growth or conversion for each of the diet categories tested. These included diets based on fish meal, fish meal plus added water, frozen fish, and ensiled fish. The silage-based diet produced comparable growth rates once the fish had become accustomed to it. Hildingstram (1976), who was employed by a feed manufacturer, found that a dry, commercially made feed produced faster growth, better conversion and lower mortalities than frozen wet feed when fed to Atlantic salmon. Solberg (1976) found that rainbow trout in fresh water grew faster on both a semi-moist diet and on an industrial fish based diet than on a dry diet. In a series of experiments conducted on turbot, Brown (1980) found that moist diets produced consistently better growth rates than dry diets, and found that out of a variety of species tested, sprat (Sprattus sprattus) produced the highest growth rates. Norwegian salmon farmers report a growth difference that favours wet feeds against dry feeds (Edwards, 1977; Edwards, 1979; Crampton and Oakley, 1981). Danish trout farmers do not report such a marked difference, and most Norwegian trout farmers find growth rates on dry diets to be similar to those on moist diets.

The reason for these differences (assuming they do exist) almost certainly lies in the palatability of the diets. Osmotic stress may be partially relieved by the intake of fresh water as a feed constituent, but the amount of fresh water in the feed is very much less than the water a fish needs to consume when in the sea. Shehadeh and Gordon (1969) found that rainbow trout drink about 0.54 per cent of their body weight of sea water per hour. To obtain this amount of water solely from a diet containing even 70 per cent moisture, a fish would have to eat 18.5 per cent of its body weight per day. On the basis of consuming 3 per cent of its body weight of a 50 per cent moisture diet, the fish would get less than 9 per cent of the amount of water it drinks. Thus it seems that osmotic stress is likely to have only a minor role in any increase in intake or growth rate.

Poston (1974) working on brown trout, and Bromley (1980) working on turbot, both found that dietary water content did not affect dietary dry matter intake, dry matter conversion or growth rate. Therefore, it seems likely that it is the inclusion of unprocessed fish which may explain the elevated levels of intake and growth reported by Norwegian salmon farmers. For this reason, experimental diets chosen have been based on frozen industrial fish and silage made from the same. In this country, the dry diets are invariably used in salmon culture, and for this reason, a dry diet was chosen for comparison with the moist diets. With the exception of Hildingstram (1976), no other reported work has used a dry diet as a control/comparator in such an investigation of salmon.

Atlantic mackerel (Scomber scombus) was chosen as the industrial fish because of its relatively low price, its high nutritive value (especially with regard to its oil content) and because it allows a comparison of feed source that is impossible with the use of filleting waste.

The choice of experimental fish species is determined by the value of the fish at harvest. The natural choice is Atlantic salmon, since they do have a higher market value and they seem likely to respond well to moist diets. Salmon farms in the UK are situated in remote areas along the North West coats of Scotland, and their remoteness from fish meal and fish diet manufacturers, allied to their relative proximity to fishing ports further enhances salmon as a choice of experimental fish species.

In order to work on salmon as the experimental fish species, it was necessary to go to a salmon farm, since existing sea water experimental facilities in this country were not available for use. Working on a farm was also seen to be useful as an education in both the practical aspects of making moist diets on a large scale, and in the practical difficulties in producing market-sized salmon. However, before proceeding with an experiment on a salmon farm, it was decided to conduct a pilot study on rainbow trout under experimental conditions. It was also necessary to examine some of the problems relating to the use of silage as a major feed ingredient for fish. The results of these two aspects are described in the following chapter.

CHAPTER 14

NUTRITIONAL PROBLEMS ASSOCIATED WITH ENSILED FISHERY WASTES

1. Problems associated with the use of silage

a) Preparation of the mackerel silage

In order to assess properly the problems involved with the use of silage as an ingredient in fish diets, some fresh Atlantic mackerel (*Scomber scombus*) was ensiled using 3.5 per cent (v/w) formic acid (85 per cent) after being minced through a disc with 4mm diameter holes. Before addition of the acid, the mackerel sample was taken and analysed for proximate composition. The results are given below :

TABLE 34 : Proximate analysis of Atlantic mackerel used in studies of the storage of silage

Protein	17.1
Oil	21.7
Ash	2.0
Water	58.4
	99.2

Protein : Kjeldahl method ; N x 625
Oil : Soxhlet method with ether extraction
Ash : 24 hours at 450°C
Moisture : 24 hours at 105°C

Analyses conducted by Aynsome Laboratories Ltd., Cumbria.

Oxidation of oils

A high level of oil is associated with prime condition mackerel and it makes the fish one of high nutritive value. However, it also means that the oxidation of oils in the silage becomes particularly important. The process of oxidation is described well in Hardy (1980) and Ackman (1980); Watanabe and Hashimoto (1968) and Fowler and Banks (1969) have both described symptoms of ill health in fish as a result of feeding oxidised oils to fish. Ethoxyquin has been used as an antioxidant in some reports of fish silage manufacture (e.g. Rungruangsak and Utne, 1981) but no account is given by these authors of its effectiveness.

For this reason, the development of rancidity of samples of mackerel silage containing various levels of ethoxyquin was investigated by measuring the peroxide value and free fatty acid levels. The silage was made by the addition of 3.5 per cent (v/w) formic acid (85 per cent); the levels of ethoxyquin added were zero, 100ppm, 200ppm and 300ppm. The results are shown in Table 35.

TABLE 35 : Effect of the addition of ethoxyquin on peroxide value and free fatty acids of mackerel silage at 0, 2, 5, 15 and 30 days after manufacture

Days after manufacture	Peroxide value of ensiled mackerel containing Zero ethoxyquin	100ppm ethoxyquin	200ppm ethoxyquin	300ppm ethoxyquin
0	2.5	1.3	1.4	2.0
2	20.0	1.5	1.5	2.5
5	25.0	1.6	1.6	2.8
15	26.0	1.5	1.6	2.6
30	37.0	1.8	1.7	2.8

TABLE 35 CONTINUED

Free fatty acids (as % of oleic acid). Days after manufacture	Zero ethoxyquin	100ppm ethoxyquin	200ppm ethoxyquin	300ppm ethoxyquin
0	0.52	0.39	0.37	0.40
2	0.56	0.50	0.39	0.45
5	0.56	0.50	0.43	0.42
15	1.24	0.68	0.56	0.73
30	1.40	0.73	0.67	0.78

Peroxide value : AOAC XII edition, 1975, p.489. Oil extracted by Soxhlet method.

Free fatty acids : AOAC XII edition, 1975, p.490. Oil extracted by Soxhlet method.

All analyses conducted by Aynsome Laboratories, Cumbria.

Table 35 shows that ethoxyquin was effective in preventing the development of peroxides. This would suggest that the addition of ethoxyquin at any of the levels shown above would be highly effective in preventing the development of peroxides, and so negating the oxidation of fats. For this reason, it was decided to incorporate ethoxyquin in silage intended for use in experimental feeds; a level of 200ppm was chosen to ensure adequate protection from the risk of oxidation.

The nutritional problems associated with free fatty acids is of less significance. Firstly, it seems likely from the work of Patton and Benson (1975) and other workers (see review by Cowey and Sargent, 1979) that fish hydrolyse lipids in the intestine to free fatty acids and the lipids are then transported across the intestine wall in this form. This is supported by evidence of the ability of fish to utilise hydrogenated fish oils (Takeuchi et al., 1979; Austreng et al., 1980).

It therefore seems unlikely that the feeding of free fatty acids in place of their bound counterparts will present any nutritive disadvantage. Furthermore, the low levels of free fatty acids found in the mackerel silage would also indicate that it is unlikely to become a serious nutritional problem.

c) Production of free amino acids

Possibly of greater importance is the conversion of proteins to free amino acids which has been shown by a number of workers to occur within the ensilage process (see Tatterson and Windsor, 1974; Backhoff, 1976; Gildberg and Raa, 1977; Strøm and Eggum, 1981). There would be a serious nutritional problem if fish were unable to utilise free amino acids. However, Aoe et al. (1974) have shown that rainbow trout (unlike carp) are able to utilise casein hydrolysates as efficiently as casein itself, implying that trout are able to use free amino acids. This conclusion is supported by the work of Rumsey and Ketola (1975), Poston et al. (1977) and Dabrowski and Wojno (1977). However, in one of these quoted works (Rumsey and Ketola, 1975) the authors reported that the improvement in growth rate only occurred when the diet was supplemented with at least five amino acids. Supplementation with only one, two or three amino acids, using various combinations, had no effect upon growth. There is no known explanation for this occurrence. However, it is known that free amino acids enter the blood stream via the gut wall faster than do dipeptides or oligopeptides (Smith, 1970; Matthews, 1972; Ingham and Arme, 1977). Hence, the supplementation of a diet with only a small number of amino acids is likely to alter the pattern of absorption which may significantly alter the pattern of amino acids available for metabolism. This, in turn, may result in the use of essential amino acids for energy or conversion to other amino acids. Since silage does contain free amino acids, this point may be of relevance. However, the point is a theoretical one, and since the level of dietary protein provided by the mackerel silage in these experimental diets is low, it is likely to be of only minor importance.

d) Loss of tryptophan

A further difficulty with the use of silage is the possible loss of tryptophan. Backhoff (1976) has shown that this does occur to some extent (e.g. 20 per cent loss in cod silage after 54 days at 15°C, and 10 per cent loss in herring silage after 42 days at 15°C). The requirement for this essential amino acid has been estimated by Mertz (1972) to be approximately 2g per kg of dry diet for chinook salmon (*Onchorhynchus tshawytshca*). For each of the levels of ethoxyquin added to the mackerel silage, tryptophan levels were measured at zero and thirty days after manufacture. These are shown in Table 36.

TABLE 36 : Effect of the addition of ethoxyquin upon the level of tryptophan in mackerel silage stored for 30 days

Tryptophan level (%)	0ppm	100ppm	200ppm	300ppm
After 0 days	0.18	0.18	0.18	0.18
30 days	0.13	0.17	0.17	0.17

Micro-biological assay after Barton-Wright (1952).
Analysis conducted by Aynsome Laboratories, Cumbria.

It would appear that tryptophan loss is reduced to an insignificant level by the use of ethoxyquin. It is not known why tryptophan loss is related (as it seems) to oxidation, but it is noticeable that Backhoff found tryptophan loss to be higher in herring (a fatty fish) than in cod (a white fish). It is unlikely that these losses will have a significant effect on the nutritive quality of the final diet since the losses are small, and since the silage will provide only a small percentage of the total dietary protein.

e) Loss of thiamine

Many fish contain thiaminase, which destroys thiamine when the fish is stored. The mackerel silage was, therefore, analysed for thiamine content at zero and 30 days. The results are shown in Table 37.

TABLE 37 : Effect of the reduction of ethoxyquin upon the level of thiamine in mackerel silage stored for 30 days

Thiamine levels (ppm)	Zero ethoxyquin	200ppm ethoxyquin
After 0 days	4.4	4.4
After 30 days	4.4	4.4

Microbiological assay after Barton-Wright (1952)
Analysis conducted by Aynsome Laboratories Ltd., Cumbria.

No loss of thiamine was detectable after thirty days. This finding is in agreement with Grieg and Gnaedinger (1971) who tabulated the presence or absence of thiaminase for many fish species, amongst them mackerel. They found it to be absent in Atlantic mackerel.

Other Considerations

A major problem that may occur with the use of silage as a major ingredient is the acid taste that the final diet will have. This will depend upon the amount of acid used in the silage, and the amount of silage used in the diet. The optimum pH value for maximum palatability to the salmon is not known, but it is unlikely to be much different from pH 7, since this is the value of their natural feed. It is possible that the most important effect that the acidity will have is during the changeover period from a neutral pH diet to an acidic one. Bromley and Smart (1981) and Rungruangsak and Utne (1981) fed diets containing 1.35 per cent and 1.5 per cent acid(W/W), and both found that after a difficult period of acclimatisation to the silage diet, intake levels were comparable to other diets tested. In the diets envisaged for this work, a 25 per cent inclusion of silage would represent an acid content of 0.88 per cent (v/w) equivalent to 0.72 per cent (W/W). Despite this lower level of acid inclusion in the diet, it was decided that an acclimatisation period of at least two weeks would be used.

It is of considerable importance that fish feed pellets are water stable, since diets that disintegrate before being eaten by the fish will return poor conversion ratios and poor growth rates. Two alginate binders produced by Protan og Fagertun, Norway, were procured and in tests in the laboratory, found to be suitable. These two binders, AG66 and AG67, had been specially developed by this company for fish feeds, the former for silage and also fish meal plus water-based feeds, whereas the latter is designed for frozen fish based diets. These binders were used in both the salmon and trout experiments. Their commercial use in Norway, and their successful use in other moist feed experiments (e.g. Solberg, 1979) would suggest that they do not produce any nutritional problem.

2. Effect of silage and moist diets on the growth of rainbow trout

In order to highlight any potential problems which might occur with the use of silage and moist diets, a pilot study using rainbow trout was first conducted.

a) Materials and Methods

The experiment was conducted using three treatments with five rainbow trout (*Salmo gairdneri*) per treatment. The fish were divided into three groups and acclimated to the diet for 14 days. The fish were weighed at the start of the experiment and after four weeks, at the end of the experiment. The fish were kept in a partially enclosed recirculating system at ambient temperature ($11^{o}C \pm 2^{o}C$) and fed to satiation twice daily during weekdays, and once daily at weekends. No proximate analyses of fish carcases were conducted.

Table 38 shows the composition of the diets : they consist of 50 per cent dry ingredients and 50 per cent moist ingredients. The moist portion varied with the diet and consisted of frozen mackerel, ensiled mackerel, and fish meal plus fish oil plus water for diets A, B and C respectively. The diets were frozen after manufacture and stored frozen until twenty-four hours before use.

Table 39 gives the results of proximate analysis of these diets on an as-fed basis, and on a moisture free basis. The diets were designed to be isonitrogenous and isocalorific on a dry weight basis, with the control diet to be used in the salmon experiment.

TABLE 38 : Composition of diets used in the pilot study with rainbow trout as the experimental species

Ingredient	Diet A (Frozen Mackerel)	Diet B (Ensiled Mackerel)	Diet C (Fish meal fish oil and water)
Danish herring meal[1]	19%	19%	19%
Norseamink[1]	7%	7%	7%
Capelin meal[1]	7%	7%	7%
Soya bean meal	6%	6%	6%
Wheat middlings	6.5%	6.5%	6.5%
Cod liver oil	1%	1%	1%
Mineral and vitamin mix	1.5%	1.5%	1.5%
Alginate binder(AG66)	-	2%	2%
Alginate binder(AG67)	2%	-	-
Frozen mackerel	50%	-	-
Ensiled mackerel	-	50%	-
Danish herring meal	-	-	12%
Cod liver oil	-	-	9.5%
Water	-	-	28.5%
Total	100%	100%	100%

[1]Fishmeal made from whole fish.

TABLE 39 : Proximate analysis of diets used in the pilot study with rainbow trout as the experimental species

	Diet A As-fed basis	Diet A Moisture free basis	Diet B As-fed basis	Diet B Moisture free basis	Diet C As-fed basis	Diet C Moisture free basis
Protein	35.5%	52.0%	35.1%	52.3%	34.4%	51.5%
Oil	15.2%	22.2%	15.6%	23.3%	14.8%	22.2%
Ash	8.2%	12.0%	8.2%	12.2%	9.1%	13.6%
Moisture	31.7%	-	32.9%	-	33.2%	-
NFE (by difference)	9.4%	13.8%	8.2%	12.2%	8.5%	12.7%

Protein : Kjeldahl method; N x 6.25

Oil : Ether extraction by Soxhlet method

Ash : 24 hours at 450°C

Moisture : 24 hours at 105°C

NFE (Nitrogen Free Extract) by difference.

b) Results

Table 40 shows the average initial and final weights and the average specific growth rates over the four-week period. None of these was significantly different for each of the diets. The feed conversion ratios on an as-fed basis and on a dry weight basis are also given.

TABLE 40 : Growth and conversion of trout fed diets containing either frozen mackerel, ensiled mackerel or fish meal plus fish oil plus water

	Average initial weight(g) ± S.D	Average final weight(g) ± S.D	Specific growth rate ± S.D	Feed conversion ratio	
				As-fed basis	Moisture free basis
A (Frozen Mackerel)	382.4^{a} ± 35.9	454.1^{a} ± 41.0	0.62^{a} ± 0.25	2.13	1.45
B (Ensiled Mackerel)	385.8^{a} ± 28.0	460.8^{a} ± 61.8	0.64^{a} ± 0.45	1.77	1.19
C (Fish meal plus fish oil plus water)	371.6^{a} ± 31.7	454.8^{a} ± 57.4	0.72^{a} ± 0.53	1.77	1.18

Common superscripts denote values not significantly different at the 0.05 level (students' t-test).

Conclusions

These results indicate that there is unlikely to be any major problem with the use of moist or silage diets for trout. Because only a small number of fish have been used over a short time, it is not possible to draw any further conclusions.

CHAPTER 15

EFFECT OF FEEDING MOIST DIETS UPON THE GROWTH RATE OF SALMON

1. Introduction

The choice of salmon as the experimental species was explained in the previous chapter. This choice meant that the experiment had to be carried out on a commercial salmon farm since no experimental facilities existed in the UK for work upon salmon in sea-water. This required the manufacture of feed and the purchase of raw materials on a much larger scale than in earlier laboratory experiments. The weighing and counting of fish also represented problems not usually encountered in the laboratory. Working on a salmon farm, however, provided valuable experience of the difficulties in producing and feeding moist diets, and in rearing of salmon to market size. It is also important that a diet intended for use on commercial salmon farms should be shown to be effective under such conditions.

2. Materials and Methods

The fish species used were Atlantic salmon (Salmo salar), and these were cultured in 300m^3 hexagonal floating cages without walkways, manufactured by T.S. Skretting A/S, Norway. Four cages were available for use ; the farm was owned by Crofter Seafoods Ltd., Skye, Scotland. The experiment was carried out from February to April 1981 ; all fish had been transferred to the sea during the previous summer. The fish were accustomed to the diet over a period of 21 days. The experiment itself lasted for 55 days, after which the fish were re-accustomed to the comparator diets. Weather permitting, the fish were fed to satiation twice daily during week days and once daily during weekends.

The moist ingredient in one experimental diet was frozen Atlantic mackerel ; the other experimental diet contained frozen mackerel and ensiled mackerel in equal proportions. The mackerel was obtained from Conon Cold Storage, Conon Bridge, a different source from the mackerel used in the pilot study. A sample of minced mackerel was analysed for proximate composition. The results of this are given in Table 41.

TABLE 41 : Proximate analysis of mackerel used as an ingredient in experimental moist diets for salmon

	Percentage in diet
Protein	15.0
Oil	28.4
Ash	2.1
Moisture	55.6
Total	101.6

Protein : Kjeldahl Method ; N x 6.25
Oil : Ether extraction by Soxhlet method
Ash : 24 hours at 450°C
Moisture : 24 hours at 105°C.

This batch of mackerel had a higher fat content than that used in the pilot study with rainbow trout. Consequently, the composition of the dry ingredients was slightly modified (see Table 42).

TABLE 42 : Composition of the experimental moist diets for salmon used in the field trial conducted on a salmon farm in Scotland

Ingredient	Diet A Frozen mackerel	Diet B Ensiled mackerel
Norseamink[1]	15.5%	15.5%
Provimi 66[2]	11%	11%
Herring by-products	7.5%	7.5%
Blood meal	4%	4%
Soya bean meal	6.5%	6.5%
Wheat middlings	1.5%	1.5%
Expawheat (includes Canthaxanthin)	0.5%	0.5%
Mineral & vitamin mix	1.5%	1.5%
AG66 (alginate binder)	-	2%
AG67 (alginate binder)	2%	-
Frozen mackerel	50%	25%
Ensiled mackerel	-	25%
Total	100%	100%

The dry mix components were milled, mixed and bagged into 25kg sacks in Scotland by Edward Baker Ltd.
[1]Fishmeal made from whole fish. [2]Fishmeal made from fish offal.

Diet B contained 25 per cent silage and 25 per cent frozen fish, in preference to a fully silage-based diet, to ensure that there would be neither an acceptability problem nor the risk of a serious financial loss to the farmer. The mackerel silage was made by mincing freshly thawed mackerel through a plate with 4mm diameter holes, using a Hobart mincer, and mixing this with 3.5 per cent formic acid (85%) to which had been added enough ethoxyquin to give a concentration of 200ppm in the mackerel silage. The mackerel plus acid/ethoxyquin was mixed in a cement mixer. Sufficient mackerel silage was made to last throughout the experimental period, including weaning on and off the diet. The silage was allowed to ensile for one month at ambient temperatures (winter in NW Scotland) before use. On a calculated basis, the moist portions of the control diet provided 20 per cent of the protein and 80 per cent of the lipid.

The main comparator diet chosen was Tess Salmon Diet, No.6 pellet size, manufactured by T.S. Skretting A/S, Norway, and was a high oil content diet. The dry mix components were designed so that when added to the frozen mackerel or frozen/ensiled mackerel, it would produce a diet isonitrogenous and isocalorific to the Tess diet. In order that a further comparison could be made, a second comparator diet, Fulmar Salmon Diet, No.6 pellet size, manufactured by Marine Harvest Ltd., Edinburgh, was used.

At the start of the experiment over 4,000 fish were counted into three of the four cages. The fourth cage contained significantly fewer fish and consequently was fed the second comparator diet. During the course of the experiment, the cage containing the fish on the Tess diet was destroyed in high winds, and unfortunately, the use of the Tess feed as a comparator was forced to be abandoned.

The proximate compositions of the diets which were used throughout the experimental period are shown in Table 43, and are given on a moisture-free basis. The moisture content shown in parentheses is the moisture content on an as-fed basis. The protein to oil ratios of Diets A, B and C are substantially different. It is unlikely that this will have a significant effect on growth since the fish are fed to satiation. Any differences that do occur would probably favour diet C, since the protein to energy ratio is highest in this diet; if the fish are eating to a set energy level, it is possible that the fish on Diets A and B will not obtain sufficient protein. However, work on protein to energy ratios (e.g. Lee and Putnam, 1973) suggests that if the fish are fed to satiation, the level of protein to energy ratio is unlikely to influence growth rate provided the ratio is within set limits, as these diets were.

TABLE 43 : Proximate analysis of moist experimental diets and the dry comparator diet used in the field trial with Atlantic salmon

	Diet A Frozen mackerel	Diet B Ensiled mackerel	Diet C Fulmar
Protein	55.3%	54.0%	58.7%
Oil	23.1%	24.9%	16.4%
Fibre	1.8%	2.0%	1.8%
Ash	13.6%	16.5%	15.6%
(Moisture)	(33.2%)	(31.4%)	(10.2%)

Protein : Kjeldahl method ; N x 6.25

Oil : Ether extraction, Soxhlet method

Ash : 24 hours at 450°C

Moisture : 24 hours at 105°C

The experimental diets were made daily in the afternoon for use on the following day. This procedure involved first mincing freshly thawed mackerel through a plate with 4mm diameter holes, using a Hobart mincer, then mixing the minced mackerel with the dry components and, if applicable, the silage, using a cement mixer. The resulting paste was then pelleted through a plate with 10mm diameter holes, using a Hobart mixer. The feed was then ready for use. For most of the experimental period, the salmon were fed 50kg of experimental feed per cage per day (25kg per cage per day at weekends). This was found, by experience, to be sufficient for satiation. The fish on the control diet were also fed to satiation, but required only 25kg per cage per day ($12\frac{1}{2}$kg per cage per day at weekends).

The fish were weighed by removing from the cage a randomly selected sample of fish and placing them in a tank containing fully oxygenated sea-water. The tank was then taken to land and the fish weighed in groups of four, without the aid of anaesthetic. The minimum number of fish weighed at each weighing was 64. At the end of the experiment, six fish from each cage were removed and their livers fixed for histological examination, and their carcases used for organoleptic tests.

3. Results

From the first day of feeding the experimental diets, it was noticeable that the salmon on these diets appeared to be more voracious feeders than the fish on the comparator feeds. Activity of fish on the experimental diets at the surface was more intense and more prolonged during feeding. Before the experimental diets were fed, there was no noticeable difference in feeding activity between the cages of fish.

Table 44 shows the initial and final weights, the average specific growth rates, and the respective standard deviations of the fish on each diet. The averages apply to the weight or growth rate of the individual fish. As the fish were weighed in groups of four, the standard deviations of the weights of the groups has been corrected by multiplying by the square root of the number of fish in each group (in this case, multiplying by two) to obtain an estimate of the true population standard deviation. This is the standard deviation shown in the table.

TABLE 44 : Growth rates of Atlantic salmon fed either a moist experimental diet or a dry commercial diet

	Average initial weight(g) ± S.D	Average final weight(g) ± S.D	Average specific growth rate ± S.D.	Number of fish weighed
A (Frozen mackerel)	717 ± 185	928 ± 312	0.463[a] ± 0.83	72
B (Ensiled mackerel)	547 ± 97	865 ± 182	0.833[b] ± 0.87	72
C (Fulmer diet)	520 ± 148	677 ± 271	0.474[a] ± 0.63	64

Superscripts represent significantly different results at the 0.01 level using the Z test.

Since the initial weights were substantially different, it is not possible to draw any statistical conclusions from the final weights. However, the growth rates indicate that the fish fed the ensiled mackerel diet produced significantly better growth rates than those fish fed either of the other two diets. Table 45 shows the feed consumption and conversion on these diets.

TABLE 45 : Feed conversion ratios of Atlantic salmon fed either a moist experimental diet or a dry commercial diet

	Feed consumed (kg) as-fed basis	Feed consumed (kg) moisture free basis	Number of fish	Feed conversion ratio as-fed basis	Feed conversion ratio moisture free basis	Average daily feeding rate moisture free basis(as % body weight
A (frozen mackerel)	2,150	1,437	4,084	2.49	1.68	0.78
B (ensiled mackerel)	2,130	1,460	4,062	1.65	1.13	0.94
C (Fulmar diet)	1,130	1,014	2,850	2.53	2.27	1.08

The results indicate that the diet containing ensiled mackerel produced significantly better growth rates than either of the two other diets. A 75 per cent increase over the comparator diet was obtained by the use of the silage based diet. There was no significant difference in the growth rate between the comparator diet and that based on frozen mackerel. These growth differences are also reflected in the conversion ratios (see Table 45).

It is evident that there is a significant increase in the growth rate of those fish fed the silage based diet, although some of the increased growth may be due to sampling errors. Neither is it certain that the increase in growth rate is due to elevated palatability or moisture content of the silage based diet, though an explanation based on differences in the protein to energy ratio seems unlikely. This is because although there is a difference in this ratio since all the fish were fed to satiation, the protein sparing effect of fat will be irrelevant. Furthermore, diets A and B both had the same protein: energy ratio and produced growth rates significantly different from each other. The only difference between diet A and diet B is the replacement of the frozen mackerel portion by ensiled mackerel. It is unlikely, however, that the measured 75 per cent increase in growth could be maintained over the entire period for which a salmon is reared in the sea (two years). However, it may be concluded that salmon grow faster on a silage based diet than on the dry diets generally available in the UK.

In view of the finding with the silage-based diet, it is surprising that the frozen mackerel-based diet did not also improve growth rate. This may be due to the higher palatability of the silage diet since at these relatively low moisture contents, the water-soluble silage may prove to be advantageous. Pellet formation and stability was certainly better with the silage diet than with the frozen diet, but the most likely cause lies with the oxidation of the frozen mackerel. Despite the fact that the mackerel was stored at -25^{o}C, it showed signs of rancidity, some of the oils migrating to the surface. The partial thawing on transport from the seller (Conon Cold Storage, Conon Bridge) to the storage point during the experiment (Scotia Frozen Foods, Portree) and the poor functioning of the freezer compressor during early storage accounts for the development of rancidity. Since the frozen mackerel provided 87 per cent of the lipids in diet A, it is likely that the wet fish portion did not have a growth stimulatory effect. The silage diet contained only 25 per cent frozen mackerel, and so was less dependent on this as a source of lipid. The frozen mackerel showed no sign of oil migration when the silage was made (soon after transport to Portree).

It is noticeable that the cages on the experimental diet had higher stocking densities than the cage on the comparator diet (97 per cent higher than the comparator in the case of diet A at the start of the experiment). It is known that increasing stocking densities leads to decreased growth rates (Refstie and Kittelsen, 1976; Refstie, 1977). Hence, it may be argued that since diet A produced similar growth rates to the comparator diet when fed to fish under a higher stocking density, diet A does have a better growth promoting potential than the comparator diet.

Clearly, a silage-based feed produced a marked improvement in both intake and growth rate of salmon. However, there are still a number of problems which need attention. The development of rancidity in frozen high fat fish is particularly a problem when the fish needs to be transported, often in unfrozen lorries, or when stored for a long time with the serious chance of a mechanical failure of the freezer.

Feeding moist diets is also more difficult than dry diets. Apart from the time and cost in making the diets, they are bulkier and more difficult to handle; both important considerations on a farm, and especially when working at sea. Furthermore, there are no suitable feeders for use with moist feeds. Pozar (1968, 1980) reports on the construction of automatic feeders for use with moist feeds, but neither machine seems likely to withstand commercial usage on cage-based systems. A further problem is the clogging of the bottom of the cages with uneaten feed. This results in a build-up of faeces and feed, a restriction of water movement, and the development of areas of low oxygen content in the water. The risk of a disease caused by toxins in the feed is also higher with the use of moist feeds.

One advantage with the use of moist feeds is that it allows better husbandry of the fish; since the fish come to the surface more for the feed and since the feed sinks more slowly, and the fish are more visible at feeding time than with the use of dry feeds.

Sections of the livers of six fish from each treatment taken at the end of the experiment were fixed for histological examination. No difference in the condition of the livers was apparent between the treatments, and no sign of liver degeneration was apparent in any of the treatments. It seems unlikely that formic acid has an adverse effect upon the pathological state of the fish when included in the diet at this level, and for the period of the experiment. Organoleptic tests revealed no noticeable differences between treatments.

4. Conclusions

This experiment indicates that salmon do grow well on moist diets and in particular on a silage-based moist diet. Whether this growth rate can be maintained over longer periods is unproven, although it seems safe to assume that the salmon should be able to maintain at least a third of the measured difference between the silage diet and the comparator. I will, therefore, proceed on the assumption that a diet such as diet B can produce a 20 per cent increase in growth rate over the comparator diet. This would return a harvest size of 5.14kg as opposed to a harvest of 3.5kg; such a harvest size is comparable to that obtained by Norwegian salmon farmers using moist diets.

The next stage is an analysis of the costs involved in producing a silage-based feed. Once an estimate of the cost of such a diet is made, then one can determine whether it would be advantageous for a salmon farmer to use a silage-based diet.

CHAPTER 16

ESTIMATION OF THE COST OF MOIST DIETS

1. Introduction

There are two major sources of feed fish for use in moist diets. Firstly, industrial fish, by-catch and undersized fish (fish that are legally large enough for sale, but command only a low price because of their marginal size). Secondly, waste from filleting operations. As we have seen, there are two methods of storage : ensiling and freezing.

Sprat and mackerel are two low-priced, high quality industrial fish. Their main disadvantage is their seasonal availability. They are ideally suited to ensilage since storage in frozen form over a long period leads either to some fat degeneration, or the requirement for more expensive methods of freezing, or packaging before freezing. The irregularity, high prices and relatively small quantities of by-catch and undersized fish means that the use of either of these is a less attractive proposition.

Filleting waste is available throughout the year, and because it contains very little fat (and fairly low levels of protein), it is more suitable than sprat or mackerel for freezing. Thus, an examination of the costs of moist diets will be made for ensiled industrial fish and frozen filleting waste.

2. Ensiled industrial fish

Sprat or mackerel could be purchased during the season and ensiled and stored in a silo for up to twelve months. The mackerel season lasts from August to October; in those three months, in 1979, over 100,000 tonnes were landed in Scottish ports, with Ullapool landing over 82,000 tonnes (DAFS, 1979). The average price at first sale was under £100 per tonne. The sprat season lasts from October to March; in those six months, 1979-80, 12,000 tonnes were landed, primarily on the East coast. The prices fluctuated around £60 per tonne at first sale.

The amount of fish necessary to form the silage component of the diet is very small in relation to these landings. A salmon farm producing 50 tonnes of salmon a year, returning a conversion ratio on an as-fed basis of 4.0, such a farm would require 200 tonnes of feed, or around 50 tonnes of silage if it were to form 25 per cent of the diet. Such amounts are very small in relation to the amounts landed and would not influence the price offered; anyone buying industrial fish for this purpose would be a "price-taker".

As has been shown in Chapter 6, the value of unprocessed industrial fish is very high; mackerel containing 25 per cent lipid and 17 per cent protein valued at £400 per tonne and £260 per tonne respectively would be worth £133 per tonne. Sprat containing 14 per cent lipid and 17 per cent protein, on the same basis, would be worth £104.4 per tonne.

It would be possible to buy both mackerel and sprat in season to reduce the maximum storage time to around seven months. However, in order to be cautious in cost evaluation, it is assumed to be necessary to store the silage for up to twelve months. Estimating the purchasing and building cost of two 30-tonne silos, an industrial mincer, pump and mixer to be £15,000, a pay-back period of seven years at an interest rate of 18 per cent per annum, the total cost of ensilage and storage would be £79 per tonne for a 50 tonne per year operation. This calculation is based on estimates provided by manufacturers of slurry storage silos, and using the capital recovery factor in discounting the capital costs of such a store (see Appendix 7). The fish will be transported from the fishing port to the farm; this will add about £10 per tonne (assuming the farm is on, or close to the mainland). The addition of the formic acid and ethoxyquin will add about £18 per tonne. At present, mackerel is a more valuable fish than sprats; we may assume a purchase price of up to £50 per tonne.

TABLE 46 : Estimated cost, at farm, of ensiled Atlantic mackerel

Cost of mackerel	£50 per tonne
Cost of acid and ethoxyquin	£18 per tonne
Machinery for making and storing silage	£79 per tonne
Transport to farm	£10 per tonne
Total	£157 per tonne

This brings the price of the mackerel above its nutrient value, previously shown to be £133 per tonne. However, its main value is in the palatability it lends to the diet.

3. Frozen filleting waste

Filleting waste is currently valued at around £20 per tonne in Scotland, block freezing costs around £35 per tonne and storage of frozen goods around £1.50 per tonne per week (Conon Cold Storage, Conon Bridge, Inverness, and considered reasonable by others). We may start with the assumption that the frozen filleting waste is purchased from the East coast and transported to the farm, where it will be stored for up to a month before usage. Transport costs will be higher since the individual loads carried will be smaller, and since the distance to be transported is likely to be greater; one can assume £15 per tonne. The cost of transport has been obtained from local haulage contractors. The cost of a freezer store to hold up to 4.5 tonnes will be about £3,000. Assuming a life of three years, an interest rate of 18 per cent, and a usage of 50 tonnes per annum, the machinery costs of storage will be about £28 per tonne. We may also assume a nominal electricity cost of £2 per tonne (£1 per week, average storage time of two weeks).

TABLE 47 : Estimated cost, at farm, of frozen filleting waste

Cost of filleting waste	£20/tonne
Cost of freezing	£35/tonne
Cost of storage (electricity only)	£2/tonne
Cost of storage (machinery only)	£28/tonne
Cost of transport	£15/tonne
Total	£100/tonne

The nutritional value of filleting waste containing 15 per cent protein and 0.5 per cent lipid is apparently £61.30 per tonne; the cost of storage and transport is out of proportion to the actual cost of the waste itself. However, as with the ensiled mackerel, its value is in the palatability it lends to the diet.

4. Cost of the prepared diet

The cost of the prepared diet will be the sum of three ingredients (silage, frozen waste and dry material) plus the cost of preparation. One may assume the dry mix will cost approximately £380 per tonne, including transport. This is somewhat lower than a pelleted diet since it does not need to be pelleted or over-oiled, and since oil is included at a lower level. We may assume the cost of facilities for diet preparation to be in the region of £10,000 (Hobart Manufacturing Co., Coventry; Tess Aquaculture, Newport, Shropshire). Discounting this over five years at 18 per cent using the capital recovery factor, this computes to £16 per tonne at 200 tonnes per year. Assuming it is necessary to employ one man full-time at £160 per week to make the diet (4 tonnes per week), the total cost of the diet preparation is £16 + £40 = £56 per tonne.

A commercial dry diet, on the farm costs around £425 per tonne which, on a moisture free basis, computes to a cost of £472 per tonne (assuming 10 per cent moisture). The moist diet is, therefore, £5.30 per tonne more expensive than a dry diet, both considered on a dry-weight basis. This is an increase of 1 per cent. It is necessary to examine what effect the expected 20 per cent increase in growth rate will have in conjunction with the 1 per cent increase in feed costs.

TABLE 48 : Summary of estimated costs of moist pellet manufacture on a typical Atlantic salmon farm

Cost of ensiled mackerel	£157 x 0.25	£39.25
Cost of filleting waste	£100 x 0.25	£25.00
Cost of dry ingredients	£381 x 0.50	£190.00
Cost of ingredients		£254.25 per tonne
Cost of preparation - machinery		£16.00 per tonne
Cost of preparation - labour		£40.00 per tonne
Cost of preparation		£56.00 per tonne
Total cost of diet on an as-fed basis (35 per cent moisture)		£310.25 per tonne
Total cost of diet on a moisture-free basis		£477.3 per tonne

CHAPTER 17

EFFECT OF MOIST DIETS UPON THE PROFITABILITY OF SALMON FARMING

We are now in a position to use Figure 9 shown in Chapter 12 of this thesis. For the dry diet, a feed element cost of £1.17 per kg. can be expected; this would be equivalent to a diet cost of £425 per tonne, and a feed conversion of 2.75. The conversion ratio given allows for the feed consumed by the grilse and mortalities, and is consequently somewhat higher than the conversion ratio of each of the fish that have survived to market-sized salmon. It implies that each kg of salmon costs £1.17 to produce from feed alone. The average harvest size for most salmon farms in Scotland is approximately 3.5kg. which implies an average specific growth rate at transfer of 1.71 per cent. Using these parameters, and others discussed in Figure 9, we would expect the farmer to make a profit of about £1.09 per kg.

Similarly, we can calculate how much profit a farmer using moist diets would expect to make. If the farmer were able to maintain a 20 per cent increase in growth rate over the dry diet, this would imply a specific growth rate at transfer of 2.05, and a harvest size of 5.14kg. It has already been estimated that the cost of a moist diet will be £477 per tonne on a dry weight basis. In calculating the feed cost element of a dry commercial diet, a moisture free feed conversion ratio of 2.48 was used. It is likely that the feed conversion ratio will increase with increasing growth rate; it may be answered that an increase of 20 per cent in the feed conversion is returned; that is a moisture free feed conversion ratio of 2.97.

Using these assumptions, the feed cost element of a moist diet would be £1.42 per kg of salmon produced. Using the two parameters, the farmer could expect to make a profit of around £2.63 per kg of salmon produced. This is an increase of 142 per cent in profit which has been attained through a 20 per cent increase in growth rate, and a 21 per cent increase in feed element costs.

The most important benefit of moist diets is that it allows the farmer to realise the higher market prices available for the largest salmon. Should this pricing structure change, the use of moist diets may become a marginal proposition. However, even a complete change to the use of moist diets for salmon in this country is unlikely to significantly effect the pricing structure due to the international supplies of farmed and wild salmon.

It seems likely, on this basis, that the use of moist diets would prove to be more profitable to the farmer than the use of dry diets. Major problems still to be resolved are whether the growth increase can be maintained over the growing period in the sea, whether silage-based diets will lead to physiological damage, and whether the costs and difficulties outlined here are realistic ones. These, and other aspects require further investigation, but it seems possible that moist diets may prove to be more profitable to salmon farmers than the currently used dry diets. There is also considerable potential for their use as feeds for other farmed demersal fish such as turbot (see Brown, 1980), eels, Dover sole and sea bass.

CHAPTER 18

GENERAL SUMMARY AND CONCLUSIONS

1. The use of semi-moist feeds for rainbow trout in this country is, at present, unlikely to have commercial application for the following reasons :

a) There is no growth or conversion advantage in feeding rainbow trout diets containing unprocessed fishery products or with elevated moisture contents. No consistent and significant differences in specific growth rate or dry matter feed conversion ratio were apparent in an experiment in which fish were fed diets of different moisture contents and diets containing unprocessed fishery products.

b) The use of costly anti-mycotics to ensure that the diet is shelf-stable is unnecessary in the production of semi-moist diets. It was shown that one of the most widely used anti-mycotics, propylene glycol, had a growth depressing effect on fish when included in the diet.

c) No saving in the overall cost of the diet is likely through the use of unprocessed fishery wastes included in a semi-moist fish diet. In a financial appraisal, it is estimated that a semi-moist diet is likely to be approximately £26 per tonne more expensive to a fish farmer.

2. The use of fishery wastes as a feeding attractant for rainbow trout is unlikely to be commercially applicable because of the

following reasons :

a) No consistent increase in intake or growth rate of trout fed a diet containing ensiled fishery wastes as a feeding attractant was evident. Despite the fact that in an initial experiment, rainbow trout did display elevated intake levels and growth rates when they were fed diets containing ensiled fishery wastes as an attractant, this result was not confirmed in two subsequent experiments, primarily due to the difficulties in feeding to satiation.

b) Fish do not find diets which have been spray-coated with ensiled fishery wastes more palatable than diets which are uncoated. In a series of trials using demand feeders, fish did not preferentially select feed from feeders stocked with such feeds.

3. The use of fishery wastes as a major ingredient in moist diets for Atlantic salmon is likely to have commercial application for the following reasons :

a) The use of ensiled fishery wastes (in partial replacement of fish meal) as a major feed ingredient does not appear to have serious nutritional disadvantages. Salmonids can effectively utilise both the free amino acids and the free fatty acids produced during the process of ensilage. The process of oxidative rancidity can be halted through the use of an anti-oxidant (ethoxyquin). No serious loss of amino acids or vitamins seems to occur in stored silage.

b) Salmon fed on a moist diet displayed elevated growth rates in comparison to a dry diet. This experimental diet consisted of 50 per cent dry ingredients, 25 per cent ensiled mackerel and

25 per cent frozen mackerel. The fish fed this diet grew 75 per cent faster than fish fed the comparator dry diet in a trial that was conducted on a commercial salmon farm.

c) The use of moist diets is likely to return a higher level of profitability to a salmon farmer than would the use of a dry diet. Despite the fact that the moist diet envisaged would be more expensive (by approximately £5 per tonne), it is estimated that due to an increased harvest size, the use of such a diet would increase profitability.

4. Growth models for trout and salmon farming are also presented and it is estimated that :

a) An increase in the specific growth rate of rainbow trout would be only slightly more effective in increasing the profitability of farming this species than a similar decrease in feed costs. This is firstly because of the relatively short growth cycle of trout in comparison with salmon, and secondly, because of the fact that the market price for trout does not increase with fish weight.

b) An increase in the specific growth rate of Atlantic salmon would be very much more effective in increasing the profitability of farming this species than a similar decrease in feed costs. This is because of the long growth cycle of Atlantic salmon, and the higher prices paid for Atlantic salmon with increasing market size.

APPENDICES

APPENDIX 1

MEASUREMENT OF THE GROWTH RATE OF FISH

A. Fish, like any other growing animals, will increase their weight in an approximately exponential manner; this will hold approximately true if the time period is short and if the fish are not approaching maturity. For this reason, the growth rate of fish is thought to act in an equivalent manner to a compound interest formula. This is given by

$$FS = I.S\,(1 + \frac{i}{100})^n$$

where FS is the final weight of the fish (at $t = t_1$)

I.S is the initial weight of the fish (when $t = t_o$)

i is the specific growth rate

and n is the number of days between t_1 and t_o. In terms of i, the specific growth rate. This may be expressed as

$$i = \left[\left(\frac{FS}{IS}\right)^{1/n} - 1 \right] \times 100$$

B. Other workers have used the value of G given by

$$G = \frac{\log_e(FS) - \log_e(IS)}{n} \times 100$$

The value of i and G are very similar; e.g. if

Final size = 150g

Initial size = 50g

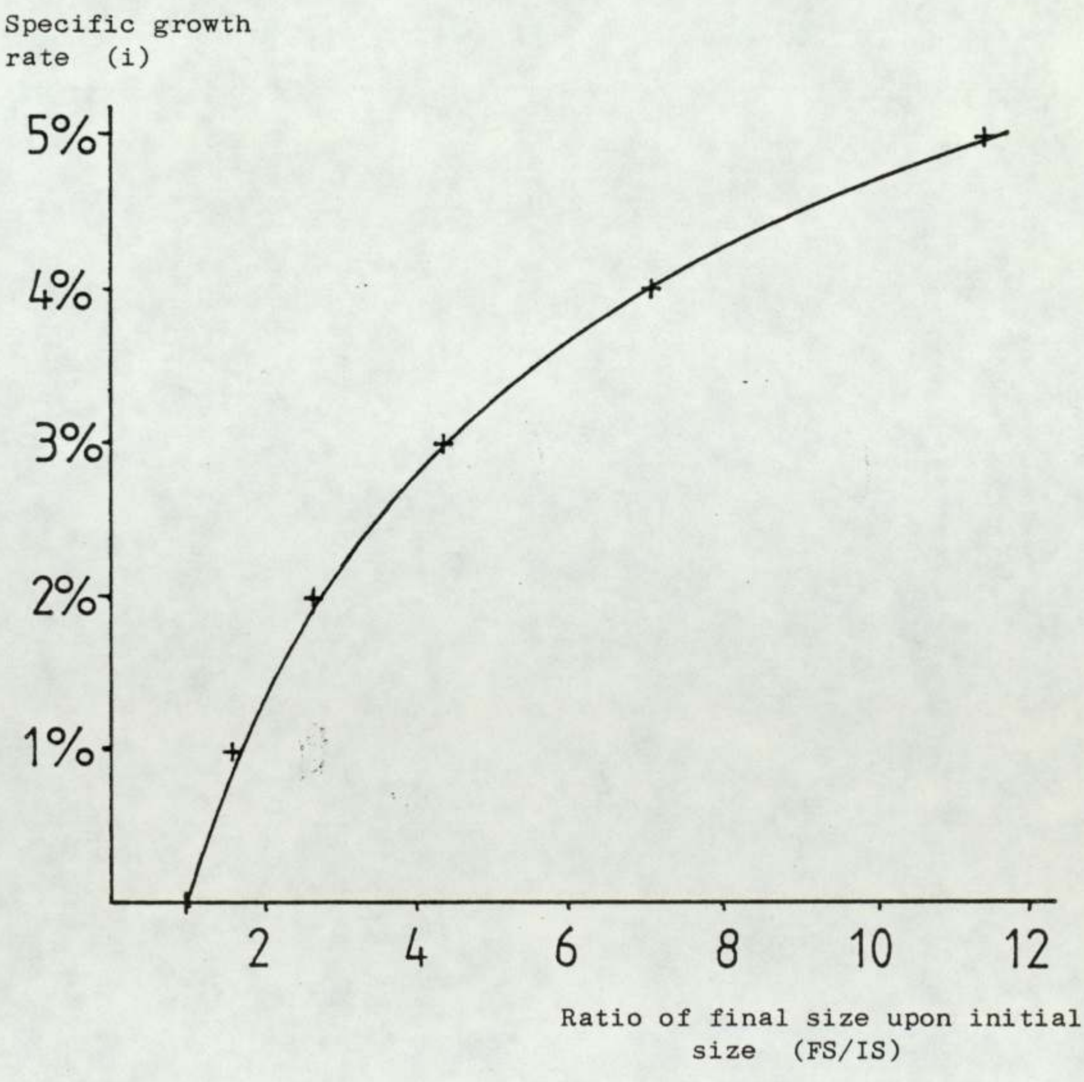
and n = 50 days

Then i = 2.22% per day

and G = 2.20% per day.

C. It should be noted that when calculating the average specific growth rate of a tank of fish from the average initial and average final weights, the figure arrived at is not exactly equal to the average specific growth rate of the same tank of fish calculated by computing the specific growth rate of each fish and then averaging these values. This is because the relationship between the final size upon the initial size (FS ÷ IS) and the value of the specific growth rate of a fish (i), for any given time period, is not a linear one. This is illustrated in the figure below.

Relationship between the ratio of the final size upon the initial size of a fish and its growth rate over a period of 50 days



In taking the ratio of the average final size upon the average initial size, one is assuming that the relationship shown above is a linear one. The size of the discrepancy between the two calculated values will depend upon the spread of the values of FS/IS and upon their position along the curve shown above. The table below illustrates how the discrepancy occurs.

Initial size (g)	Final size (g)	Ratio of FS to IS	Specific growth rate
100	100	1.000	0
100	164.5	1.645	1
100	269.2	2.692	2
100	438.4	4.384	3
100	710.7	7.107	4
100	1146.7	11.467	5
Average 100	471.6	4.716	2.5 3.15

for n = 50 days

Average of individual growth rates = 2.5

Growth rate of average sizes = 3.15

The discrepancy (3.15 vs 2.5) is large in this case since the range of individual growth rates is large. Such a wide spread is not likely to be typical of the growth of salmonids in experimental conditions. However, the example does illustrate how the discrepancy arises. For experiments shown in this work, the discrepancy should be small.

The discrepancy also occurs, and for the same reason, when using "G" as a measure of growth rate.

APPENDIX 2

RESULTS OF THE PROXIMATE ANALYSIS OF CARCASES OF FISH IN THE FIRST EXPERIMENT DESIGNED TO ASSESS THE NUTRITIVE VALUE OF WHOLE, UNPROCESSED MACKEREL

Figures given are the mean levels from the analysis of eight fish for each figure given.

Analysis	Diet	Initial status	Intermediate status	Final Status
% Moisture	Control	74.19 a	^{a}74.18 a	^{a} 73.04 b
	Small S.M	a	^{a}74.19 a	^{a} 73.03 b
	Large S.M	a	^{a}74.64 a	^{a} 72.75 b
% fat of dry weight	Control	27.94 a	^{a}29.19	^{a} 28.78 b
	Small S.M	a	^{a}26.46 a	^{ab} 28.23 b
	Large S.M	a	^{b}25.41 a	^{ab} 28.91 b
% Ash of dry weight	Control	7.76 a	^{a} 7.82 a	^{ab} 7.83 a
	Small S.M	a	^{b} 8.61 b	^{a} 7.80 a
	Large S.M	a	^{b} 8.50 b	^{b} 8.38 a
% protein of dry weight	Control	54.39 a	^{a}55.45 a	^{a} 56.00 a
	Small S.M	a	^{b}59.24 b	^{a} 57.28 a
	Large S.M	a	^{b}58.96 b	^{a} 58.38 b

Moisture = 24 hours at 105°C

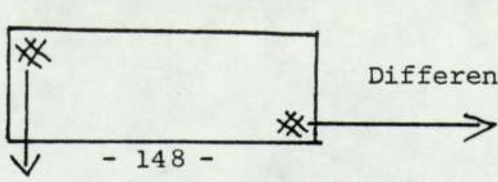
Fat = Ether extraction by Soxhlet method

Ash = 24 hours at 450°C

Protein = Kjeldahl method ; N x 6.25

Different letters in each box imply significantly different results at the .05 level as computed using the two-tailed students' t distribution. Those letters in the top left-hand corner apply to variations produced through different diets for a given point in time. Those in the bottom right-hand corner reflect changes produced over time for a given diet. The diagram below may help to illustrate the point.

Differences due to type



Differences due to time

APPENDIX 3

TOTAL VIABLE COUNTS, MOULD AND YEAST GROWTHS AND PRESENCE OF COLIFORMS IN SAMPLES OF SEMI-MOIST DIETS TAKEN AT TWO-WEEKLY INTERVALS DURING THE SECOND EXPERIMENT UPON THE NUTRITIVE VALUE OF WHOLE, UNPROCESSED MACKEREL

Week	Total viable counts $20^{o}C$ ($37^{o}C$) counts per gram			Mould growths (Yeast growth) c/g			Coliforms per 10 ml		
	D	E	F	D	E	F	D	E	F
2	6000 (3000)	40 (20)	5400 (3800)	10 (10)	10 (10)	10 (10)	+	+	+
4	1420 (5200	3400 (3200)	7000 (2700)	10 (10)	10 (10)	10 (10)	+	+	+
6	1300 (1800)	100 (600)	3800 (3500)	10 (10)	10 (10)	10 (10)	+	+	+
8	1520 (2000)	1010 (600)	1000 (710)	100 (10)	10 (30)	10 (20)	+	-	+

Total viable counts and coliforms cultivated using Ringer solution.

Moulds and yeasts cultivated using Malt Extract Agar.

APPENDIX 4

TOTAL VIABLE COUNTS, MOULD AND YEAST GROWTHS AND COLIFORM PRESENCE IN SAMPLES OF SEMI-MOIST DIETS TAKEN AT WEEKLY INTERVALS DURING THE EXPERIMENT UPON THE EFFECT OF PROPYLENE GLYCOL UPON STORAGE STABILITY

Weeks after manufacture	Diet type	Total viable counts (counts/gram) $20^{\circ}C$	$37^{\circ}C$	Moulds (c/g)	Yeasts (c/g)	Coliforms per 10 ml
	G	44,000	17,000	60	40	+
3	H	11,000	21,000	60	70	+
	I	9,400	24,000	40	30	+
	G	11,400	12,900	110	80	-
4	H	12,000	12,600	170	80	-
	I	1,200	2,400	40	10	+
	G	17,800	10,000	400	300	+
5	H	11,200	4,000	100	60	-
	I	8,000	1,440	70	30	-
	G	4,700	1,680	20	10	+
6	H	3,700	2,300	10	30	-
	I	7,000	2,400	20	10	-
	G	2,400	1,500	10	10	-
7	H	200	500	10	10	-
	I	300	300	10	10	+
	G	1,100	100	10	10	-
8	H	1,700	600	10	10	-
	I	400	100	10	10	-
	G	15,200	1,500	5,840	10	-
9	H	900	1,600	600	10	-
	I	400	600	20	10	-

Total viable counts and coliforms cultivated using Ringer solution.

Moulds and yeasts cultivated using Malt Extract Agar.

APPENDIX 5

COMPUTER PROGRAM (WRITTEN IN BASIC) TO PREDICT THE WEIGHT OF FISH AT 30-DAY INTERVALS FOR GIVEN INPUTS

```
10   A1  =  1.50191
20   B1  =  -0.4
30   W1  =  0.1
40   N1  =  1
50   N   =  901
60   For X  =  1 to N
70   B2  =  B1*(Log(W1))
80   A2  =  A1 + B2
90   A3  =  EXP(A2)
100  A4  =  A3/100
110  A5  =  A4 + 1
120  A6  =  A5 N1
130  W2  =  W1*A6
140  IF X =  1 then 180
150  IF D =  30 then 180
160  D   =  D + 1
170  Go to 200
180  Print X, W2, A3
190  D   =  1
200  W1  =  W2
210  NEXT X
220  END
```

This program outputs the weight at the end of the day of the fish every 30 days from Day 1 to Day 901 inclusive and the growth rate during that day. The formula used is

$$\text{New size} = \text{Old size} \left[1 + \frac{e^{a + b\log_e \text{old size}}}{100} \right]^n$$

where n = number of days between iterations and a and b are species and environmental-related parameters.

In this case

$$n = 1$$

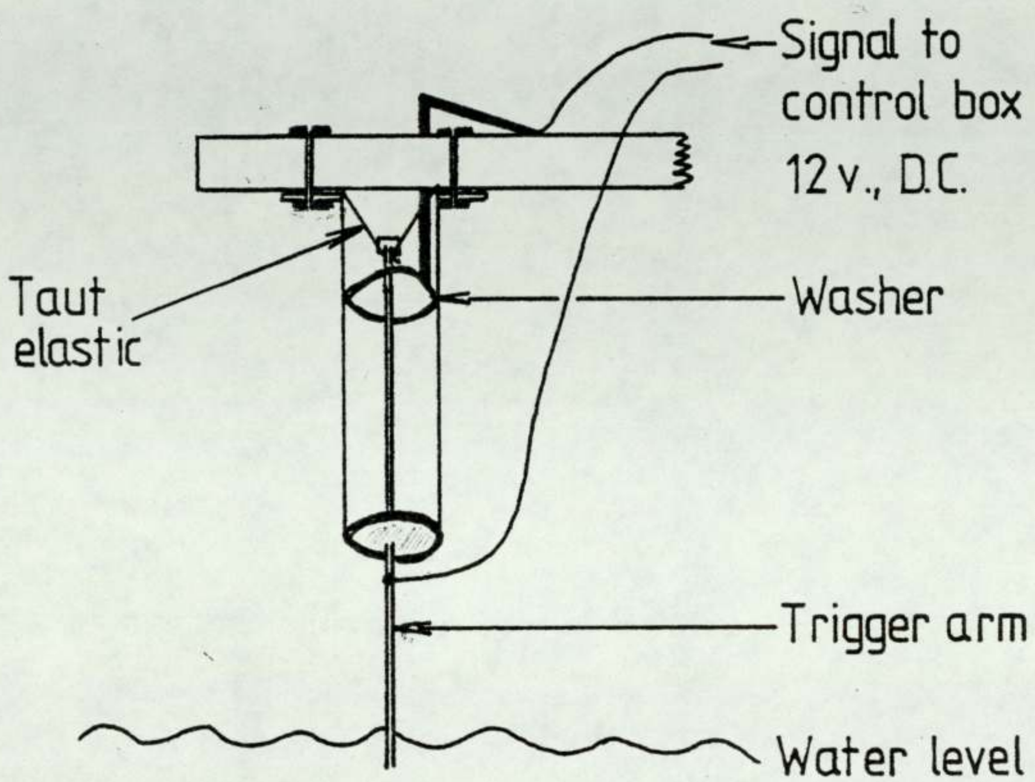
$$a = 1.50191$$

$$b = -0.4$$

$$\text{Start size} = 0.1\text{g.}$$

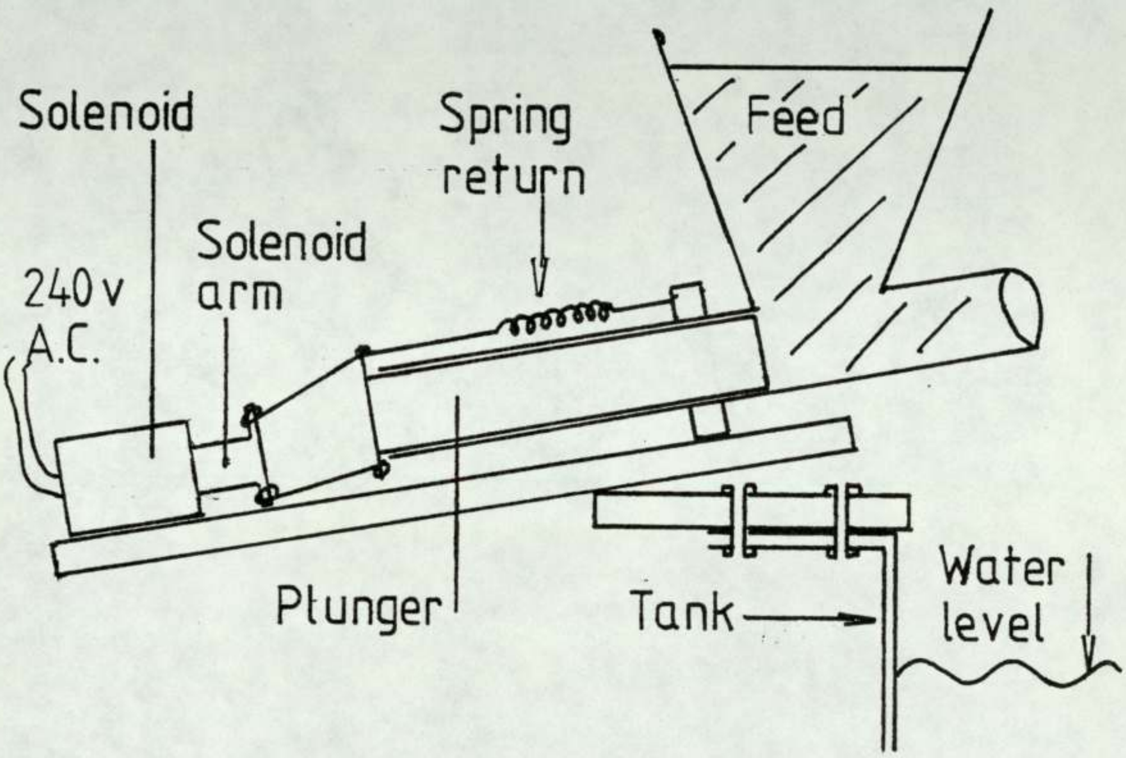
APPENDIX 6

DESIGN OF TRIGGER FOR DEMAND FEEDER (SIDE VIEW)



When the lower part of the trigger arm is moved, the upper part touches the washer, completing an electrical circuit and so sending a signal to the control box. The taut elastic ensures that the upper part of the trigger arm returns to the centre of the washer.

DESIGN OF FEEDER MECHANISM IN DEMAND FEEDER (SIDE VIEW)



The electrical signal from the control box actuates the solenoid and the solenoid arm and plunger are pulled into the solenoid housing. The solenoid holds the arm and plunger in for 0.5 secs, during which time feed takes up the space vacated by the plunger. When the arm is released, the arm and plunger return to their original position by means of the spring return, and so shoot out feed to the tank.

APPENDIX 7

INVESTMENT APPRAISAL

The capital recovery factor is the method used in this work to calculate the annual repayments a borrower (of cash) has to make on a loan for a fixed period of time. The capital recovery factor assumes that if the annual repayments made by the borrower are invested at a given interest rate, they will provide the same gain to the lender as if the lump sum had been invested for the whole period at that interest rate.

The annual repayments necessary may be calculated by the following formula.

$$AS = \frac{OS.i.(1+i)^n}{(1+i)^n - 1}$$

where AS = Annual amount repayed

OS = Original sum borrowed

i = Interest rate

n = Number of years over which the loan is made.

In all cases an interest rate of 18 per cent per annum has been used. In most cases, a repayment period of five years has been used.

For a useful text on Investment Appraisal, see Frith (1975).

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