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'Studies on the biological and economic factors involved in fish culture, with special reference to Scotland.'

by

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ABSTRACT

The intensive cultivation of fish and shellfish for human consumption has recently attracted interest in Scotland, particularly in the area whose activities are assisted by the Highlands and Islands Development Board. A study was performed to consider the biological and economic factors relevant to commercial investment in fish culture in this region. It was considered that the study should closely examine these aspects of the culture of rainbow trout (*Salmo gairdneri*). Particular attention was paid to the sequence of decisions which require to be taken when planning a trout farm. An analysis of the economic aspects demonstrated that costs are dominated by feed costs and that profitability is particularly sensitive to changes in operating costs and revenues. It would appear that investments in this field are likely to provide low discounted financial returns at the present time, especially when the high risk element is considered. Certain implications for the future of Scottish trout culture were briefly examined.

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CHAPTER I

AQUACULTURE: THE PROBLEM

1.1 Introduction

Aquaculture has been defined as the practice of growing aquatic organisms under controlled conditions (Bardach *et al.*, 1972), and this study is concerned with one branch of such activity, namely fish culture (otherwise known as 'fish farming').

Fish culture had been practised certainly as long ago as 475 B.C., when Fan Lai produced a treatise on carp culture, and was probably already established in China by 2000 B.C. (Lin, 1940). Hickling (1971) quotes a variety of sources to demonstrate that fish culture was widely practised in Britain during medieval times, to provide food for human consumption. This involved mainly the culture of coarse fish, which decreased in popularity in Britain, when transport, communications and iceing facilities improved sufficiently to enable inland markets to sell fresh sea fish at an acceptable price. This helped to bring about a change in the feeding habits and preferences of the British population so that, by the end of the nineteenth century, coarse fish had ceased to be esteemed for the table in Britain, although a few fish farms were in operation. However, the latter existed primarily to produce game fish in order to stock waters for recreational purposes, the practice of which has continued to the present day. It is only during the last decade that attention has been directed once again towards producing fish for human consumption in Britain. It is significant, however, that the majority of fish cultured recently for this purpose in Britain have been

Salmonids, which is in marked contrast to the situation in e.g. Eastern Europe, where much Carp species are currently cultured for human consumption.

The purposes for which fish culture is practised in Britain are varied and include:

i) production of food for human consumption

ii) provision of fish for recreational (sporting) purposes

iii) the replacement and/or replenishment of stocks after interference with natural fish populations, e.g. due to the erection of dams for hydro-electric or water supply purposes

iv) the rearing of ornamental and aquarium fish.

The study described here has restricted its attention primarily to the first category, i.e. providing food for human consumption.

1.2 Objectives

Since the inception of the Highlands and Islands Development Board, there have been discussions as to the rationale of including fish farming among those activities assisted by the Board. It was suggested that there might be particular natural advantages for fish farming in Scotland. However, it appeared that there was a paucity of information on both the technologies for fish farming best suited to the Scottish environment and the nature of the profit opportunities which might exist. The present study was initiated in September, 1970 in an attempt to clarify these problems, with particular reference to the area of Scotland under the jurisdiction of the Highlands and Islands Development Board.

It was conceived as being an interdisciplinary project whose objective would be to clarify the biological and economic criteria relevant to commercial fish farming. There was no intention of investigating the sociological or regional economic effects of such investments, but rather to provide information which might assist those firms wishing to make investment decisions in this field.

1.3 Methodology

Data was collected by personal interview wherever possible. A problem arose in obtaining data due to the commercial interests involved and the comparative novelty of intensive fish culture in Britain. This was partly overcome by:

i) the decision to restrict confidential information to the examiners, which was explained in a letter of introduction used at interviews (Appendix I).

ii) visiting countries where fish culture was more standard practice than in Britain. In such cases, information was often more freely available and the interviewer was not treated as a potential competitor.

Appendix II provides a list of the visits made. Although a total of 223 visits are itemized against 136 different sites, specific reference is omitted to longer stays at one Danish and two Scottish trout farms. The purpose of these extended visits was to gain an insight into the daily routines involved on different types of trout farm at different times of the year by working (without remuneration) at them.

Visits were made to locations in six European countries outside Great Britain and the Irish Republic. An attempt has been made to classify the visits according to the nature of the information derived. However, the classification is not strict and in some cases rather arbitrary, since various subjects were sometimes discussed during one or more interviews at one visit. The two main reasons for multiple visits to the same place were:

i) to observe the progress of an on-going project

ii) to gain the confidence of those who were unwilling to divulge certain information at an initial meeting.

CHAPTER 2

SELECTION OF SPECIES FOR AQUACULTURE IN SCOTLAND

2.1. Introduction

At the present time, there are a wide range of aquacultural activities throughout the world, many of which are restricted to certain localities which possess characteristics particularly suiting them to such activities (Bardach et al. loc. cit.). Any consideration of the range of aquatic animals which might feasibly be cultured for profit in Scotland, either at the present time or within the next five years, must examine the relevant resources which exist in that country. An analysis of the biological, technological and economic features of each 'candidate' species may then be related to the advantages and/or disadvantages of the Scottish locale in order to choose those species, the culture of which is most likely to prove an attractive investment in Scotland.

2.2. Scotland as a resource base for aquaculture

Scottish resources relevant to aquacultural possibilities comprise both natural and artificial characteristics, reflecting technical and economic constraints on such activities. Lindsay (1971) briefly surveyed the six counties comprising the Highlands and Islands Development Board area (i.e. Argyll, Caithness, Inverness, Ross and Cromarty, Sutherland and Zetland) as a resource base for aquaculture, and the current study is also particularly concerned with this area. However, the most profitable Scottish trout farm currently in operation (Kenmure) is located in Kirkcudbrightshire in South-west Scotland.

2.2.1. Natural resources of the Highlands and Islands area. The interaction between the geology and climate of the area in determining the ecological characteristics has been discussed by various authors. Darling and Boyd (1969) refer to the relationship between aquatic life and climate in Scotland, and claim that the latter is much more influenced by altitude than by latitude and distance from the sea. The same authors conclude that this area shows constant advance and retreat of oceanic and continental air over the mountain ranges, causing a belt of very high rainfall a few miles inland, where rainfall exceeds potential evaporation in every month of the year. In the midwest, the land comprises ranges of sharp peaks and narrow ridges either side of deep valleys, in contrast to the plateau effect over much of the northwest. The catchment areas of the many lochs of the region show great variation, but the short west coast rivers north of Loch Linnhe have a generally small catchment area and exhibit rapid fluctuations in flow rate, i.e. they are typically spate rivers. Water engineers often assume a dry weather flow for highland streams of 0.1 ft^3/sec. per 1,000 acres. However, examination of specific sites will often indicate drought flows which do not achieve this figure. Semple (personal communication) collected nine sets of data from engineering studies (Table 1) and in only two of the nine streams studied, did the dry weather water flow exceed 0.1 ft^3/sec. per 1,000 acres. The Highland fresh water systems are primarily based on surface run-off; they are generally poor in mineral salts and are usually acidic., due to the peaty subsoil overlying predominantly igneous rock. Freshwater

TABLE 1

Dry weather water flows recorded at nine sites in relation to catchment area (after Semple: personal communication)

Site	(inches)	Catchment area (acres)	Dry weather waterflow (ft^3/sec.)	Dry weather waterflow (ft^3/sec./ 1,000 acres)	Source of readings
Kilblaan burn tributary, Glen Shira	90	96.6	0.001	0.014	Babtie, Shaw and Morton (1947)
" " (upper reaches)	90	917.7	0.032	0.035	"
Allt-an-Taillir (upper reaches)	110	1387	0.038	0.027	"
Allt-an-t-Sithein (upper reaches)	105	1199	0.198	0.165	"
Brannie Burn (upper reaches)	100	1663	0.226	0.136	"
R. Shira (upper reaches)	100	2881	0.221	0.077	"
R. Fyne (upper reaches)	110	12057	1.03	0.086	"
R. Thurso	35	92800	8.3	0.09	Binnie, Deacon and Gourlay (1947)
Allt Druisdale (Skye)	-	460	-	0.023	Ornsay (1955)

temperatures are usually rather low because of the altitude and short length of most watercourses etc., and annual temperature ranges are commonly ca. 1°C. - 16°C.

Two important factors affecting the climate of the Highlands and Islands are the North Atlantic Drift - the northern sweep of the Gulf Stream current, and the marked indentation of the coastline such that the sea often penetrates deeply into the countryside. The average yearly sea water temperature range at Loch Fyne was 6 - 16°C over a period of 3 years (McCrone, personal communication), and this is reflected in the air temperatures of the adjacent land. In general, sea water temperatures on the Scottish west coast exceed those on the east coast, particularly during the winter season (when fresh water temperatures tend to be near freezing point). The west coast sea lochs are predominantly fjordic, i.e. long, narrow bodies of water with an entrance sill which is shallow compared to the average depth of the loch. The rainfall and run-off into Scottish sea lochs usually exceeds evaporation rates, giving rise to a surface layer of low salinity, and circulation within the loch is influenced mainly by sill-depth, tidal range and wind-effects (Milne, 1972).

On the west coast, a not inconsiderable fishery for Herring (*Clupea harengus*) exists throughout the year and is currently taken mainly by midwater pair-trawling and purse-seining. Mackerel (*Scomber scombrus*) are a common species inshore in Summer but, like Herring, are probably under-exploited due to lack of demand. Of the Gadoid species, the Common Cod (*G. morrhua*) and Haddock (*G. aeglefinus*) support reduced offshore fisheries, and Whiting (*G. merlangus*). Coalfish (= Saithe (*G. virens*)), and Lythe (= Pollack (*G. pollachius*)) are common inshore fish. Further out towards the edge of the continental shelf, Hake (*Merluccius merluccius*), Halibut (*Hippoglossus hippoglossus*), and Ling (*Molva molva*) are regularly fished, and large stocks of Blue Whiting (*Gadus poutassou*)occur although they have hitherto been ignored as a fishery (Bailey, personal communication). Various flat-fish and Elasmobranch species are fished regularly in the area but do not represent a large resource. Certain Sharks, Skates, Rays and also Whales are taken rarely at the present time but may not be uncommon. Valuable fisheries for Norwegian Lobster (*Nephrops norvegicus*), Scallops (*Pecten maximus*) and Queen Scallops (*Chlamys opercularis*) comprise the most commercially significant shell fish resources of the area. The Salmon (*Salmo salar*) and Seatrout (*Salmo trutta*) fishery of the west coast is not insignificant, although smaller than that on the east coast.

2.2.2. Artificial resources of the Highlands and Islands

Apart from crofting activities, the main industries of the Highlands and Islands have been concerned with sporting interests and with the fishing industry. The latter has been a critical factor in the existence and/or growth of most west coast townships, notably Gairloch, Kinlochbervie, Kyle, Lerwick, Lochinver, Mallaig, Stornoway and Ullapool and the nature of the coastline provides generally sheltered anchorages. Suitable labour exists to service the regional fishing industry, and there are road, rail and ferry links with the larger wholesale fish markets. However, facilities are generally on a smaller scale than those at the large east coast ports, e.g. Aberdeen, where there is greater continuity of supply of fishery products.

Since the inception of the Highlands and Islands Development Board in 1965, funds have been given to promote various investments in the area, including fish farming. Low rents are payable on most leased land in the region. However, new industrial development has been minor compared with the east coast, and industrial pollution is not a problem. In general, rod and net Salmon fishing in freshwater is less valuable on west coast rivers and there is consequently greater access to freshwater than on east coast rivers.

2.2.3. Discussion and conclusions

MacKenzie and Macfarlane (1970) listed the following "physical conditions which make the (H.I.D.) Board's area suitable for fish farming:

(a) the availability of large areas of unpolluted water

(b) the availability of space suitable for development

(c) the indented coastline providing sheltered sea lochs where the effects of exposure to the elements are not extreme.

(d) the ameliorating effects of the North Atlantic Drift on winter climate resulting in relatively fast growth rates and high planktonic levels in the sea.

(e) the ready availability of gradient in close proximity to good supplies of water

(f) the presence of a supply of labour amenable to fish farm employment.

(g) the existence of a fish handling infrastructure capable of adjusting itself to cultured aquatic species

(h) access to the bi-products of fish processing for utilisation as fish feed."

Of these factors, it might be considered that
(e) implies a reliability of flow which may rarely exist;
(f) implies that labour amenable to such employment is necessarily of value, whereas the requisite skills may be rather different from conventional fisheries employment;
(h) does not indicate the regularity of access to by-products which might be important. It would appear that not inconsiderable marine fishery resources exist currently in the area which could be utilised, e.g. to provide feed for certain farmed fish. However, unless fish farms are sited very close to fishing ports or centres of communication, road access and services are likely to be poor. It is likely that financial assistance from the H.I.D.B. has been an important factor in the recent establishment of commercial fish culture projects in the Board area.

It may be concluded that the natural marine resources have advantages for fish farming in the Highlands and Islands of Scotland; there are, however, certain problems associated with the natural freshwater resources and the artificial resources of this region.

2.3 Species selection

2.3.1 Introduction and historical aspects

Although culture of trout for restocking purposes had been practised in Scotland for almost a century, culture of other species is a more recent phenomenon. The possibilities for other species were first demonstrated in Scotland during the second world war. Gross (1946) found that, by fertilising an enclosed sea loch with Superphosphate and Sodium Nitrate, it was possible to grow flat fish two to four times as rapidly as in untreated waters, but his work was restricted by the scarcity of young fish for stocking, as well as the propensity of the fish to escape into the open sea.

Plaice (Pleuronectes platessa) had been cultured and stocked in Norway for 60 years (Bardach et al., loc. cit.) but, before 1962, no more than 10% of larvae in hatcheries could be reared to metamorphosis. However, it was then discovered that the main cause of heavy larval mortality was bacterial multiplication. This was obviated by the addition of antibiotics which made it possible to rear 60 - 80% of the larvae to metamorphosis (Shelbourne, 1964).

This success stimulated the White Fish Authority to initiate feasibility studies into marine fish culture, on the basis of three objectives:

i) to investigate the feasibility of augmenting fisheries by stocking flatfish fry

ii) to investigate the use of enclosed natural areas for growing flatfish, with fertilization of the water and/or supplementary feeding

iii) to experiment with intensive culture in heated water.

Since 1965, the White Fish Authority have been conducting experiments at two stations in Scotland on both flat fish and Oyster culture. Marine fish farming of other species then began to attract interest in Scotland so that one estimate of projected production for 1971 was:

100 tons of 'marine' Rainbow trout (Salmo gairdneri)
30 tons of Mussels (Mytilus edulis)
20 tons of Lobsters (Homarus vulgaris)
4 million seed Oysters (Ostrea spp.: Crassostrea spp.)

Although none of these estimates was achieved by 1971, it may be presumed that the author (Milne, 1970) did not anticipate the Scottish culture of Atlantic Salmon which took place.

2.3.2. Criteria for selection

In selecting possible species for commercial culture in the U.S.A., Bardach and Ryther (1968) listed the following characteristics of organisms which lend themselves to commercial culture:

i) ability to reproduce in captivity
ii) hardiness of eggs and larvae
iii) food requirements that are readily satisfied
iv) relatively fast rate of growth

to which list, Bardach *et al.* (*loc. cit.*) added:

v) adaptability to crowding

Gaucher (1971) in a similar analysis listed nine criteria as follows:

i) spawning and gametogenesis controllable under laboratory conditions
ii) simple larval development
iii) fast growth rate
iv) high food conversion efficiency
v) satisfactory feeds known and available
vi) indigenous to the region under consideration
vii) sold at retail in the higher price range
viii) commercial feeds available in quantity at competitive prices
ix) hardiness of the organism and resistance to the stress induced by confinement.

Mathiessen and Gates (1971), in considering regional development for aquaculture, postulated certain economic factors as being significant in species selection, namely:-

i) market price

ii) market volume

iii) inter-regional competition

iv) natural supplies

2.3.3. 'Coarse screening' of candidate species

In attempting to select species that possess good potential for commercial culture in Scotland at the present time, some of the above criteria may be used to devise a coarse screen. Thirteen candidate species were chosen based upon those species about whose culture potential the H.I.D.B. had received most enquiries. They were tested against these criteria and rated, if rather arbitrarily on the basis of points obtained, using a binomial scoring system (Table 2) It is then possible to establish a 'cut-off score', and candidate species whose aggregated scores do not achieve this level may then be eliminated from further consideration. Such a system has many problems, e.g. (i) the initial choice of animals to be screened, (ii) the difficulty in certain instances of deciding how to score an 'intermediate' case, (iii) the assumption that differing criteria are given equal weighting. Thus, it might be argued that high unit value is more significant than certain biological criteria in determining feasibility for culture (e.g. in such a screening system, high unit value might be awarded a 'bonus point' in which case, with a cut-off score of 5, Eels and Dover Soles are no longer eliminated from

TABLE 2

Scored matrix to compare the feasibility of culturing certain aquatic species in Scotland

	Controlled spawning	Simple larval development	Fast growth rate	High conversion efficiency	Satisfactory feeds known	Indigenous to Scotland	Hardy	Commercial feeds available	In higher price range	FINAL SCORE
FLAT OYSTER (Ostrea edulis)	1	1	0	0	1	1	1	0	1	6
PACIFIC OYSTER (Crassostrea gigas)	1	1	1	1	1	0	1	0	1	7
SHORE MUSSEL (Mytilus edulis)	1	1	1	1	1	1	1	0	0	7
LOBSTER (Homaris vulgaris)	0	0	0	0	0	1	0	0	1	2
FRESHWATER PRAWN (Macrobrachium rosenbergi)	1	0	1	1	1	0	0	0	1	5
SHRIMP (Pandalus spp.)	0	0	1	1	0	1	0	0	1	4
TURBOT (Scophthalmus maximus)	1	0	1	1	1	1	1	1	1	8
DOVER SOLE (Solea solea)	1	0	0	0	1	1	0	0	1	4
LEMON SOLE (Microstomus kitt)	1	0	0	0	1	1	1	1	0	5
PLAICE (Pleuronectes platessa)	1	0	1	1	1	1	1	1	0	7
RAINBOW TROUT (Salmo gairdneri)	1	1	1	1	1	0	1	1	0	7
ATLANTIC SALMON (Salmo salar)	1	1	1	1	1	1	1	1	1	9
EEL (Anguilla anguilla)	1	0	0	0	1	1	0	0	1	4

CODE: 1 - advantage; 0 - disadvantage.

further consideration, and Pacific Oysters achieve a total score in excess of Shore Mussels). If these complications are ignored, at a cut-off score of 5, the final scores are:

Score	Species
9	Atlantic Salmon
8	Turbot
7	Pacific Oyster, Shore Mussel, Plaice, Rainbow Trout
6	Flat Oyster
5	Freshwater Prawn, Lemon Sole
<5	Lobster, Shrimp, Dover Sole, Eel

2.3.4. Species evaluation for Scotland

The current state of progress in farming each of the species which passed through the coarse screen may be examined and the feasibility of profitable farming in Scotland evaluated.

(i) Culture of Atlantic Salmon

The technology for intensive farming of Atlantic Salmon and Pacific Salmon (*Oncorhynchus spp.*) advanced rapidly during the past decade with major research efforts centred in the U.S.A., U.K., Japan, Sweden and Norway. Atlantic Salmon is a luxury food in Britain and commands a high market price (Table 3). Since 1970, one company in Scotland and two in Norway have succeeded in rearing significant numbers of fish from the egg through the freshwater parr stage and then through the seawater smolt stage to marketable adults. Presmolts have achieved food conversion ratios of 1.5 - 2 : 1 (wet weight food : wet weight fish) on dry pelleted diets when reared in square or round fibreglass tanks. Postsmolts have achieved food conversion ratios of 5 : 1 when fed wet trash fish (whole or

Table 3

Range of prices paid by Scottish wholesalers for Atlantic Salmon in 1972

Source: Mace: personal communication

COMPANY I		
Salmon	75p. - 85p./lb.	(£1,680 - £1,904/ton)
Grilse	51.5p. - 61.5p./lb.	(£1,154 - £1,378/ton)
COMPANY II		
Salmon	75p. - 110p./lb.	(£1,680 - £2,464/ton)

minced) or moist pelleted diets. It has proved possible to maintain postsmolts at high stocking densities (5 kg./m^3 = 0.31b./ft^3.) in cages and nets, provided water circulation is sufficient and salinity exceeds 30^o/oo salinity. Artificially stripping broodstock fish of eggs and milk and subsequent fertilisation is simple, and 6 lb. adult fish have been reared from the egg in 3 years. At the current time with the present state of knowledge, Atlantic Salmon are likely to represent the most profitable species for farming on the west coast of Scotland. If floating facilities are used for rearing this species, it might be found necessary, in order to ensure adequate levels of high salinity, to use pumps so as to lift high salinity water from under less saline surface layers. Shrimp offals might need to be brought from elsewhere and fed unless artificial carotenoid pigments are incorporated into the feed to ensure adequate pink colouration of the Salmon flesh. Many sheltered sea-lochs would be suitable for the farming of Atlantic Salmon.

(ii) Culture of Turbot, Plaice and Lemon Sole

By 1968, a technology had been developed, following the work of Shelbourne (*loc. cit.*) and others, such that mass hatching and rearing of Plaice and Dover Sole could be performed. In the same year, the White Fish Authority commenced to use the warm water outfall at Hunterston power station (Ayrshire), where Plaice have since been successfully spawned, hatched and reared, for several successive years. Lemon Sole and Turbot have also been spawned and hatched on a number of occasions but (unlike Plaice and Dover Sole) have not yet been reared through metamorphosis at Hunterston.

Jones (1972) examined the factors to be considered in the choice of species for marine fish farming. He discussed the market value of marine flatfish and indicated the seasonal variation which occurs for these three species (being inversely related to market volume), and the influence of size and condition on market price. Table 4 gives the average values of landings of Turbot, Plaice, Lemon Soles (and Dover Soles for comparison) for England and Wales, and Scotland, for 1971 and 1972. In order to provide an indication of the rates of price inflation involved, Table 5 gives the average values of landings of these species for the last three months of 1971 and 1972.

Jones (*loc. cit.*) pointed to the interspecific differences in growth rate with Turbot exceeding Lemon Sole and Plaice, and sexual difference in the growth of Turbot. He also confirmed that Turbot may be reared satisfactorily on wet trash fish feeds or dry pelleted diets, but concluded that the former was preferable in cost/effectiveness terms; his assumption of trash fish prices @ 1.0p./Kg. (*ca.* 0.46p./lb.) cannot, however, be regarded as likely and a recent economic evaluation preferred dry pellets to wet feeds for farmed Plaice (Mace, personal communication; see Chapter 8 and Table 32).

The unit value of Plaice is likely to remain insufficiently high to provide adequate returns to intensive culture of this species unless alternative and cheaper feed sources become available. Although Turbot and Lemon Sole are more valuable, there still exists the lack of a suitable larval feed of sufficiently small particle size; the nauplii of *Artemia*

Table 4

Average values of landings of four species of demersal fish (excl. livers) landed by British vessels in the U.K. (excluding Northern Ireland) for the years 1971 and 1972 (£/ton): Source: Fish Industry Review (1973)

	England and Wales		Scotland	
Species	1971	1972	1971	1972
Turbot	537	637	493	521
Plaice	162	191	162	183
Lemon Sole	287	319	287	327
Dover Sole	688	786	-	640

Table 5

Average values of landings of four species of demersal fish (excl. livers) landed by British vessels in the U.K. (excl. Northern Ireland) for the last three months of 1971 and of 1972 (£/ton): Source: Fish Industry Review (1973)

	England and Wales	Scotland
Species	Oct. - Dec., 1971	Oct. - Dec., 1971
Turbot	560	553
Plaice	218	208
Lemon Sole	342	429
Dover Sole	737	-
	Oct. - Dec., 1972	Oct. - Dec., 1972
Turbot	711	701
Plaice	257	227
Lemon Sole	426	472
Dover Sole	1,035	860

salina, which are successfully used for Plaice, are too large for these species during initial larval feeding. It is possible to collect marine flat fish from the wild after metamorphosis under licence for experimental purposes. This was done and work at Hunterston, with warmed seawater at ca. 7°C above ambient temperature, has permitted growth rates to market size for various species (e.g. Turbot, Plaice, Lemon Sole, Dover Sole) in less than 2 years, i.e. less than half the time required in the wild. High density culture of Plaice in floating cages in a sealoch at Ardtoe (Argyll) demonstrated enhanced growth rates over wild fish, although not attaining the rates achieved at Hunterston (Howard, personal communication).

It may be concluded that the commercial attractiveness of farming Turbot, and possibly Lemon Sole, currently awaits further technological advance, particularly in larval feeding. The Scottish west coast might then comprise a suitable environment for on-growing these species, as with Plaice already. Another consideration is that the higher prices of similar alternative species, e.g. Dover Sole and Halibut, might ensure that these species are farmed preferentially, should the technologies prove transferable.

(iii) Culture of Pacific Oyster, Shore Mussel and Flat Oyster

Mollusc culture on the Scottish west coast has recently aroused some interest and obtained some financial assistance from the H.I.D.B. Good growth and high condition factors have been obtained with suspended rope cultivation of Mussels at one sealoch site (Linne Mhuirich, Argyll). However, the initially excellent spatfalls have not been sustained regularly, and other problems have arisen, e.g. Acidian species settling on the ropes, Eider ducks (*Somateria mollissima*) stripping young Mussels from the ropes (Millar; Stevenson, personal communication). Both Pacific and European Flat Oysters are being currently reared at an Oyster hatchery on Loch Creran (by Oban, Argyll). Spawning is induced by artificial warming of seawater in the hatchery above 20°C, and the Oyster larvae are reared using algal cultures. Spatfalls are then induced on plastic collectors before transferring to trays for on-growing, and *C. gigas* spat is currently being sold at 2 - 5 mm. length. Survivals are still unpredictable but it is anticipated that the process will become more successful within the next 12 months (Price, personal communication). On-growing trials of both species continue both inside and out of the hatchery.

Mussels are a low value commodity and current delivered prices ('in the shell') are £25 - £30 per ton. One company (Severnside Ltd., Patchway, Bristol) holds somewhat of a monopsony position in the British market. This limits the ability of primary U.K. producers to influence prices, unless they segment the market, e.g. by smoking, which has been attempted but with little success (Stevenson, personal communication). By contrast, Oysters are a luxury food and current wholesale prices for Pacific Oysters are (i) as spat @ *ca*. £3 per thousand, (ii) as adults for consumption @ *ca*. £40 per thousand ('in the shell'). The present U.K. requirement for Oyster seed is ca. 4 - 5 million per annum, and it is likely therefore that any future increases in spat production will need to rely on export markets (Knowles, 1973), particularly since additional Oyster hatcheries now exist at Poole (Poole Oyster Co., Dorset) and Brynsiencyn (Seed Oysters (U.K.) Ltd., Anglesey, North Wales).

A few private individuals are currently attempting to on-grow small numbers of Oyster spat at selected Scottish localities. However, even on the west coast, winter growth is poor or absent. The provision of unpolluted seawater affords the opportunity of establishing more Oyster hatcheries in this area, e.g. to produce spat for on-growing elsewhere. However, it is likely that this would require to be based on export sales, and information on production costs and profitability is lacking. Rope mussel cultivation in the area has encountered technical problems; it would require to be practised at very low cost in order to be profitable.

(iv) Culture of Rainbow trout

At the commencement of this study, intensive farming of Rainbow Trout in Scotland was already claimed to be profitable and 'an established technique of aquaculture under Scottish conditions' was claimed to exist only for 'some salmonid species' (MacKenzie and Macfarlane, loc. cit.). Thus Rainbow trout farming was examined in some depth, and is discussed in subsequent chapters, since an accurate assessment of the farming of this species as a commercial investment in Scotland was considered to be more practicable than that of other aquatic species.

(v) Culture of Freshwater Prawns

Shrimp and Prawn culture is practised, particularly in Asia, but recently considerable work has been performed on culture of temperate species native to western Europe, e.g. Pandalus borealis. Palaemon serratus (Reeve, 1969). The relatively slow growth of these species under experimental conditions, even with artificially warmed seawater, encouraged examination of other species with a faster growth rate (Walne, personal communication). Accordingly, work has continued with the giant freshwater prawn, Macrobrachium rosenbergi. of the Indo-Pacific region. Larval development requires water of 8 - 22°/oo salinity, and considerable progress has been made with prawn feeds, although under conditions of high stocking density, survival rates are still unsatisfactory (Bardach et al., loc.cit.). At two sites in England, commercial companies are currently using closed cultivation systems and heated water at ca. 28°C in order to rear M. rosenbergi on a pilot scale (Ingram, personal communication).

Forster and Wickens (1972) reviewed the status and potential of Prawn culture in the U.K. and stated that the market value of Prawns, which was difficult to assess, depended on size, whether they were shelled or not, the state of presentation (whether frozen, fresh, canned or dried), and the flavour and texture. These authors considered that the fresh unshelled market was the most valuable, although demand was likely to be restricted and exhibit seasonal fluctuations, and that prices of £1 per lb. could be achieved. In the long term, they suggested that cultured Prawns will need to compete with preserved (wild-caught) Prawns in the cocktail market at (July, 1972) prices of ca. 50p./lb. However, M. rosenbergi is of an adult size such that it might more rationally compete in the 'Scampi' (Norway Lobster) market which is less valuable per unit but considerably larger, and currently experiencing rapid price inflation (Table 6), - the average U.K. first-hand quay unit price for 1973 is likely to be in excess of 20p. per lb. Alternatively, large Prawns might be used to develop a novel U.K. market for a high quality main dish product with a higher unit price.

The suitability of the west of Scotland for large Prawn cultivation is an analogous problem to that of Oyster hatcheries, i.e. the facilities would comprise shore-based plant and the local environment would only be critical insofar as a supply of unpolluted seawater would be necessary.

2.4 Conclusions

The six counties comprising the Highlands and Islands Development Board area of Scotland possess certain resources which might be of value for the purposes of aquaculture, in particular the marine environment (sheltered sealochs with relatively mild winter temperatures, certain fishery resources, the services of a fishing industry, etc.). The criteria involved in selection of species suitable for culture have been discussed. Thirteen species, which had been considered for culture in the area were subjected to a coarse screening procedure based upon certain of these criteria. Four were eliminated from further examination, and the remaining nine species were considered individually.

At the commencement of this study (and probably still at the present time), only one candidate species (Rainbow Trout) was being cultured profitably in the area of Scotland under discussion. At the present time, the culture of two species, Atlantic Salmon and Plaice, has overcome initial technological

Table 6

Landings and Average values of Norway Lobsters landed by British vessels throughout the U.K. for 1972 and for the year ending 31st March, 1973

Source: Fish Industry Review (1973)

Year	England and Wales		Scotland		Northern Ireland	
	Volume (tons)	Average value (£/ton)	Volume (tons)	Average value (£/ton)	Volume (tons)	Average value (£/ton)
Y/E 31st Dec.1972	845	308	9,215	258	3,090	158
Y/E 31st Mar.1973	935	430	10,275	378	3,955	204

difficulties. Both species might now be cultured commercially but this is being currently explored for Atlantic Salmon only, since Plaice are regarded as having an insufficiently high unit value to cover adequately the production costs incurred. Atlantic Salmon culture would appear to be an enterprise of commercial attractiveness, for which the resources of the Scottish west coast are particularly suited. The information derived from work with Plaice has been of value in helping to establish techniques for the culture of more valuable marine flat fish. It is likely that Turbot (and possibly less valuable Lemon Sole) could be cultured profitably in the area in the near future, although further technical developments are still required. The rope culture of Mussels appears to present marketing and certain technical problems. However, Mollusc hatcheries are likely to prove commercially viable provided they can obtain adequate prices in export markets for Oyster spat. The culture of large Prawns will probably be an attractive investment in the near future although more information is required on market aspects; as with Oyster production, West Scotland would have no particular advantages for Prawn culture except for the unpolluted marine resource(and the possible availability of financial assistance, which might apply to culture of any species considered).

The culture of Salmon and Trout is likely to represent a profitable venture at the present time in the West of Scotland. The culture of certain marine fin fish and shellfish is likely to become profitable but requires further technological refinement. The relative attractiveness of the various species examined is likely to alter with ongoing progress in research and development. It is important continually to evaluate and consider alternative species which may not have been considered in detail here, e.g. Dover Sole, Halibut, but the culture of which might become an attractive investment in the area at a future date.

CHAPTER 3 TROUT: MARKET ASPECTS

It may be argued that a bioeconomic analysis of trout culture should commence with the markets, which are for restocking and the table.

3.1 Restocking Market

The 'restocking' market supplies live trout for stocking watercourses, as well as trout eggs and fry for on-growing by hatcherymen, other restocking farms, etc.

3.1.1 Trout Eggs

Trout eggs are occasionally marketed as 'Green' eggs (i.e. before the embryonic eye becomes apparent) but are commonly sold as 'Eyed' eggs. Current prices for eyed eggs are £0.75 - £1.50 per 1,000 eggs. A premium is charged for quality (viability, growth potential, etc.) and also for disease status (certification of freedom from e.g. I.P.N. and V.H.S. virus diseases).

3.1.2 Trout Fingerlings

An established market exists for fish at 3" in length (6-8 cm.). Certain farms (especially in Denmark) specialize in fingerling production as such fish are regarded as resistant to certain disease problems of smaller fry, e.g. I.P.N. virus, clinical whirling disease. Farms where such diseases are endemic commonly buy-in fish at this stage. Current prices (ex farm) in Denmark and Britain are £20 - £30 per 1,000 fingerlings.

3.1.3 Live Trout (Larger Sizes)

Prices of live trout are usually quoted per 1,000 fish at a specified length. In Britain, there is reasonable agreement in prices particularly with larger length classes. Fig. 1 indicates the length/price relationship for four British trout-farms producing Rainbow trout for restocking in

FIGURE 1

Relationship between retail prices for live trout and length per fish.

Y = Purchase price (£/1,000 fish)
X = Fish length (inches)

A, B, C and D are four trout farms in the U.K. which sell trout mainly for restocking and prices quoted are ex farm (1972).

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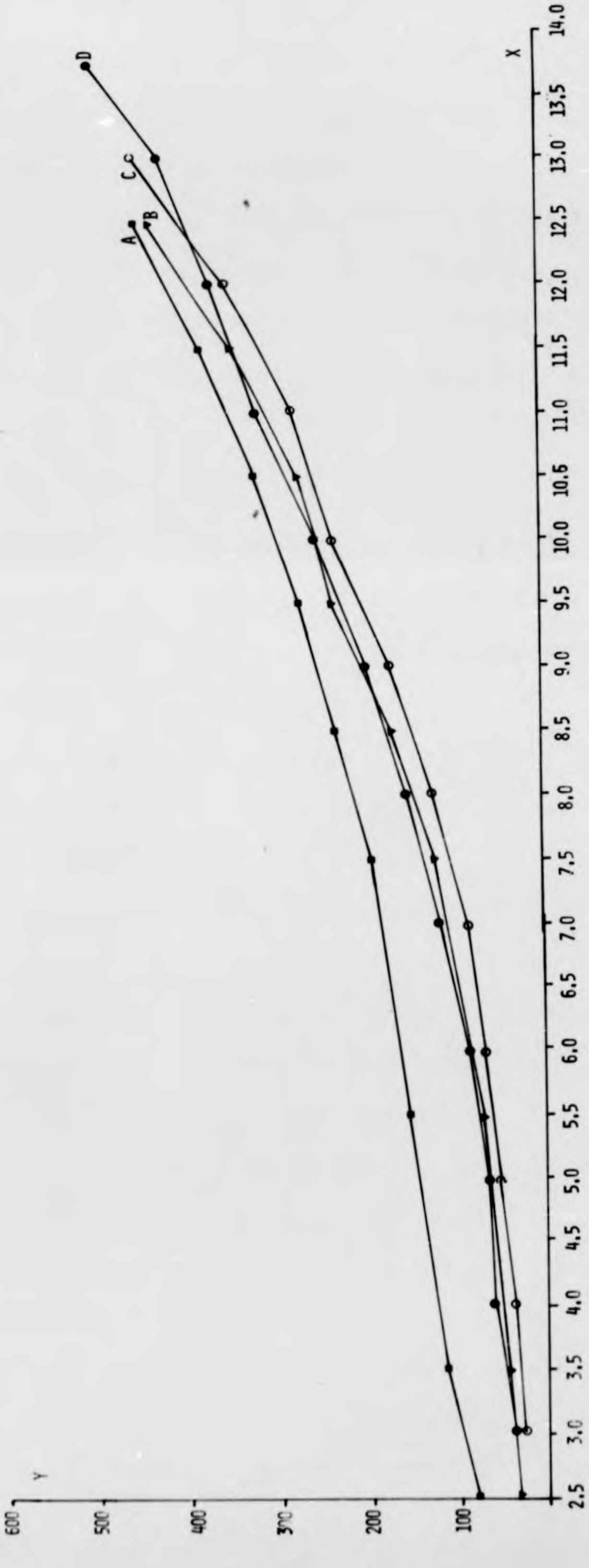


1972/73. For this sample, there would appear to be an approximately linear relationship between length and price for trout exceeding ca. 7" in length.

The current size of the British market for trout for stocking purposes is difficult to quantify. It may be inferred from the volume of feed sales as ca. 500 tons per annum (Stratford, personal communication). An unknown quantity of this market (probably > 80%) is finally fished and presumably consumed if of edible size.

3.2 Table Market

3.2.1 Introduction

The marketing aspects of trout for human consumption exhibit a variety of complications.

i) Most countries which have a significant trout farming industry consume part of their production, and export as well; they may also import trout.

ii) Trout farming statistics are difficult to obtain because (a) the industry is insufficiently large for Governments to require the collation of such data and (b) the existing farmers are unwilling to make information available since this might encourage new entrants into the industry.

iii) Most trout farming countries are expanding their production and seeking new outlets, differentiating the product, etc.

iv) The individual characteristics of the market often show marked international variations.

v) Political and economic constraints on free international marketing of trout are currently altering (e.g. E.E.C. trade barriers, U.S. embargo on Danish trout for disease reasons)

3.2.2 Volume of U.K. Market

A small and unknown volume of trout is eaten by anglers. The rest is either imported into the U.K. or produced by domestic trout farmers. Customs statistics only specify importation into the U.K. of fresh (or temporarily preserved) trout (i.e. frozen trout imports are not classified separately); production of U.K. trout farms is recorded only for Scotland. (Tables 7,9).It is possible to estimate the total markets by examining export statistics of the countries from which is derived the majority of U.K.imports (Table 8).The consumption of sea Trout will be ignored since (i) it is a small market (e.g. 250 tons of sea trout were landed in 1969), (ii) it is a seasonal market due to fishery regulations (unlike Rainbow Trout) (iii) it is in a higher price range than farmed (i.e. Rainbow)trout and has certain characteristics in common with the Salmon market, e.g. the requirement for pigmented pink flesh, etc.

It is not possible to assess accurately the annual production by trout farms in England, Wales and Northern Ireland. One may assume the same value as the corresponding annual production in Scotland, although this may be conservative (e.g. in 1971, England did not suffer the same disease outbreaks which affected Scottish production). Over the period 1967 - 1971, the accumulated values of imports and home production (actual and assumed) give a range in total consumption (Table 10)of 2,000 - 2,600 tons approximately. Over the same period, exports of trout from the U.K. were recorded only in 1970 and 1971 and these were of such magnitude (1.1 ton at £593 and 4.6 tons at £3,033 respectively) that it may safely be assumed that aggregated import and home production figures give the

TABLE 7

Imports of Rainbow Trout into the U.K. (fresh or temporarily preserved (Source: H. M. Customs and Excise)

Year	Volume (tons)	Value at C.I.F. prices (£)	Unit Value (£/ton)
1967	900	313,904	349
1968	997	347,776	348
1969	799	326,120	408
1970	676	351,251	520
1971	697	360,778	518

TABLE 8

Imports of frozen Rainbow Trout into the U.K. (Sources: Japanese Fisheries: Dansk Andels Orredeksport: Hon. H.L.Cohen)

Year	Danish Frozen (tons)	Japanese Frozen (tons)	Total Frozen (tons)
1967	550	481	1,031
1968	772	564	1,336
1969	477	680	1,157
1970	912	680	1,592
1971	818	401	1,219

TABLE 9

Scottish production of portion-size farmed Rainbow Trout (Source: Dept. of Agriculture and Fisheries for Scotland)

Table 10

Year	Approx. Production (tons)	Estimated Total annual consumption in U.K. (tons)
1967	20	1,971
1968	47	2,427
1969	85	2,126
1970	146	2,560
1971	88	2,092
1972	340	?

closest approximation to total U.K. consumption of trout that may be achieved in the absence of other statistics. It would not appear that the increase in home production, which may achieve a total of 1,000 tons for the current year, has brought about a decline in imports, i.e. there is capacity for growth in this market.

3.2.3 Products

The main trout products for the table market in the U.K. in order of popularity are:-

1. Frozen gutted
2. Fresh ungutted ('in the round')
3. Smoked (gutted)
4. Frozen ungutted
5. Live

The frozen (ungutted) and live markets are very small (total $<$ 100 tons) and will be ignored. Some imports of smoked trout occur but the majority of smoked trout is sold as frozen trout to processing companies for smoking. Thus, the U.K. market may be divided into 'Freezers' and 'Freshers'.

Frozen trout is imported from Denmark and Japan in varying proportions (Table 8) and the total market is ca. 1,000 - 1,600 tons per annum. It comes through wholesalers (notably in London and Grimsby) and is delivered by fishery companies, mainly within the catering trade to restaurants and hotels.

Fresh trout is produced by trout farmers in the U.K. and imported from Denmark and the total market is ca. 1,000 tons per annum. The majority of fresh trout passes through the wholesale fish markets (notably Billingsgate, Manchester and Birmingham) and retailed by fishmongers, etc. The main weight classes favoured are 5 - 6 oz., 6 - 8 oz., and 7 - 9 oz., but there is some demand for trout of 4 - 5 oz. and 9 - 11 oz.

A small but increasing proportion of trout (especially fresh) is being produced with pigmented (pink) flesh. An increasing proportion of gutted trout also has the gills removed at processing.

3.2.4. <u>Value</u>

Approximate current U.K. wholesale prices for whole fresh and gutted frozen trout are 32p. and 39p./lb. respectively. By comparison, live portion-size fish are 60-70p./lb., and consumer packs of smoked trout are 80 - 90p./lb. Gutting causes a weight loss of <u>ca</u>. 18 - 19%, i.e. ungutted fish at 32p./lb. would lose weight equivalent to <u>ca</u>. 6p./lb. on being gutted and would thus require to be sold at 38p./lb. in order to retain their value (assuming there is no market for trout guts).

Premiums exist for freshness of fresh trout and for Danish (over Japanese) frozen imports. At particular times, certain weight classes may be sold at a premium; usually the extremes of the preferred weight classes (4 - 5 oz., 9 - 11 oz.) are sold at a discount and 5 - 6 oz. and 6 - 8 oz. are similar in price (with 7 - 9 oz. occasionally sold at a discount).

3.2.5. <u>Markups</u> (March, 1973)

(i) Fresh Trout

e.g. Danish imports shipped to Harwich and railed to Manchester.

		Cum. price (p/lb.)
C.I.F.* PRICE HARWICH		27.0
TARIFF (8% since 1st Jan., 1973)	2.2p./lb.	29.2
LANDING AND PORT CHARGES AND AGENCY FEES	0.4p.	29.6
TRANSPORT TO MANCHESTER (B.R.)	0.6p./lb.	30.2
WHOLESALER'S MARGIN	2.0p./lb.	32.2
FISHMONGER'S MARGIN (70%)	22.8p./lb.	55

* Carriage, Insurance and Freight

(ii) Frozen Trout (gutted)

e.g. Japanese imports shipped to Liverpool and distributed in London.

		Cum. price (p/lb.)
C.I.F. PRICE LIVERPOOL		34.0
TARIFF (10% since 1st Jan., 1973)	3.4	37.4
LANDING, PORT AND AGENCY CHARGES	0.4p./lb.	37.8
DELIVERY TO COLD STORE	0.2p./lb.	38.0
WHOLESALER'S MARGIN (20%) (incl. cold store, distribution, finance, etc.	7.6p./lb.	45.6

Note (i) Sales of Danish fresh trout via Harwich to Billingsgate are usually negotiated and sold at a London price (i.e. direct to the wholesale market).

(ii) Wholesale markups are greater if it is necessary to split cases or deliver, etc.

(iii) If it is required to contract for supplies over a certain duration at a fixed price, the price is usually in excess of the going rate at the time of contract.

3.2.6.

MARKET STRUCTURE

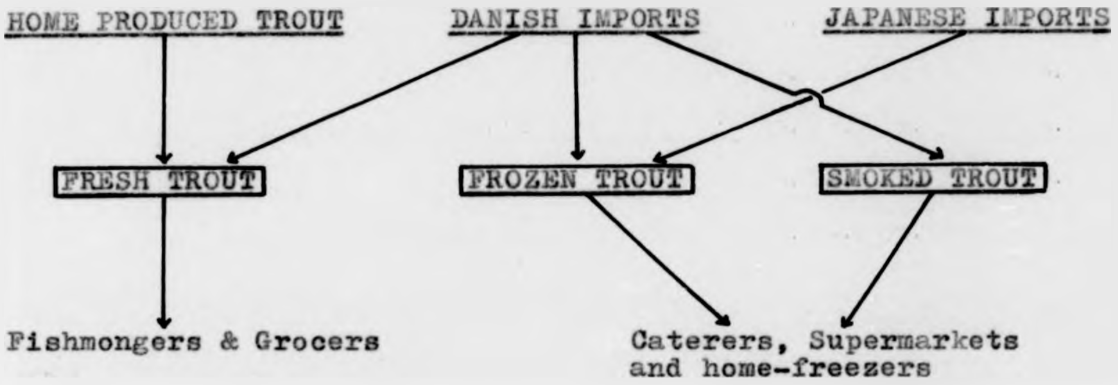


Fig. 2. U.K. market for trout. Origins, destinations and product types

(i) Fresh Trout

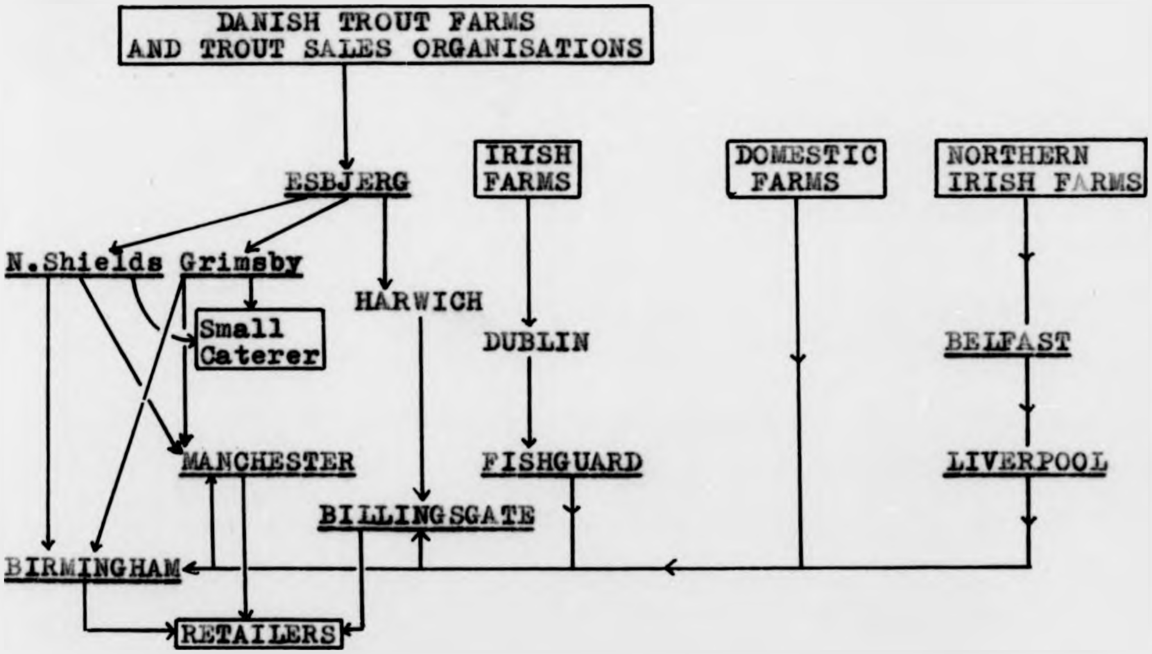
Fresh trout consumed in Britain is either home produced (incl. Irish Republic) or imported from Denmark (Fig. 2). A small volume of fresh trout is delivered direct to retail outlets (fishmongers, hotels, etc.) by domestic farmers. However, the great majority of fresh trout passes through fish wholesale markets (Fig. 3). Probably 90% of fresh trout is retailed by fishmongers and grocers, who either buy at the market or have the product delivered by the wholesaler. Billingsgate may supply as much as 80% of the trade (mainly by one company, M. Janssen Ltd.), which is probably over 90% retail.

(ii) Frozen and Smoked Trout

Frozen and smoked trout consumed in Britain is imported from either Denmark or Japan. 90 - 95% of the trade is comprised of catering sales to restaurants and hotels. Smoked trout is either imported as such or smoked after importation.

One company, Compass House Ltd. (Grimsby) handles more than 50% of the U.K. frozen trout market (Fig. 4) and possesses the agency for sales of Dantrout in this country. Various frozen food companies distribute frozen trout to the catering trade (and a small volume to retail outlets, largely supermarkets) as well as importing to a variable extent (Summary: Tables 11 and 12).

Fig. 3 <u>Transport and distribution channels for Fresh Trout marketed in U.K.</u>



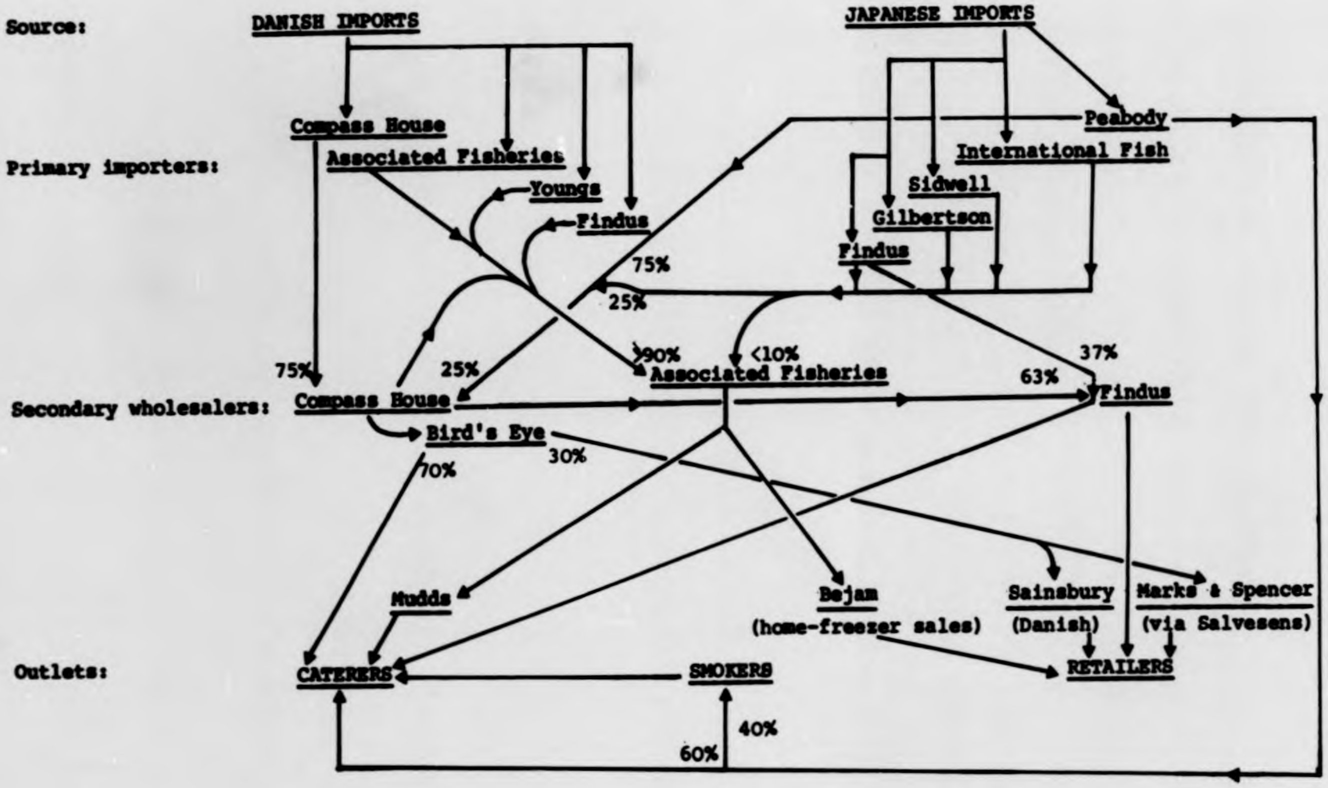


Fig.4 Flow-diagram of the structure of the U.K. market for frozen trout.

Table 11

Primary Importers of Danish frozen trout

Company (in order of importance)	OUTLET
1. Compass House	Catering and Retail
2. Associated Fisheries/Mudd	Catering
3. Youngs	Retail
4. Findus	(Jap. catering); Retail
5. Birds Eye/Smethurst	Catering
6. Ross	Catering

Table 12

Primary Importers of Japanese frozen trout

A. Before 1970 (Companies listed in probable order of importance)

1. Peabody
2. Associated Fisheries
3. Sidwell
4. Gilbertson
5. Kiril Mischeff
6. Macfisheries
7. Birds Eye/Smethurst

B. Since 1970 (Companies listed in probable order of importance

1. Peabody
2. International Fish
3. Sidwell
4. Gilbertson
5. Findus
6. Birds Eye/Smethurst
7. Macfisheries
8. Associated Fisheries

3.2.7

DEMAND

The market for trout may be divided into the retail segment (mainly fresh trout) and the catering segment (mainly frozen and smoked trout). The total market is small relative to most other fish, with an approximate annual U.K. consumption per capita of 0.2 trout (2,500 (U.K. market in tons p.a.) x 4,480 (fish/ton)/55 x 10^6 (U.K. population)), of which $>$ 50% is consumed in hotels and catering establishments. Several factors are likely to be of importance in determining demand for trout.

(i) Price

It is claimed by importers, wholesalers and retailers that the demand for trout is relatively independent of price. Trout has been traditionally regarded as a semi-luxury product with a high price relative to other fish. There is no evidence that the large wholesale price fluctuations for imports of fresh and frozen trout (Figs 5,6 & 7) have influenced annual demand which appears to be rather static. However, data is not available to calculate price elasticities of demand for trout.

(ii) Incomes

It is possible that changes in consumer incomes may influence demand for trout, White fish has an average income elasticity of expenditure of 0.3 and income elasticity of quantity purchased of zero while the figures for tinned Salmon are zero and 0.1 respectively, i.e. in these two cases, rise in incomes has virtually no effect on consumption levels (Sykes, personal communication.) Table 13 indicates that, for fresh fat fish, other than Herring (i.e. Salmon, Trout, Mackerel,

FIGURE 5

The pattern of price movements for Danish fresh trout imports to the U.K. over the period: April 1969 - April 1972.

Y = Purchase price (d./lb.)

X = Time of purchase (increments of 4 months)

Price data refers to the mean monthly unit prices paid by Compass House Ltd. (C.I.F. Grimsby) for purchased lots of ice-packed trout. Prices given are in old pence but equivalent prices in new pence are given in brackets (Y axis)

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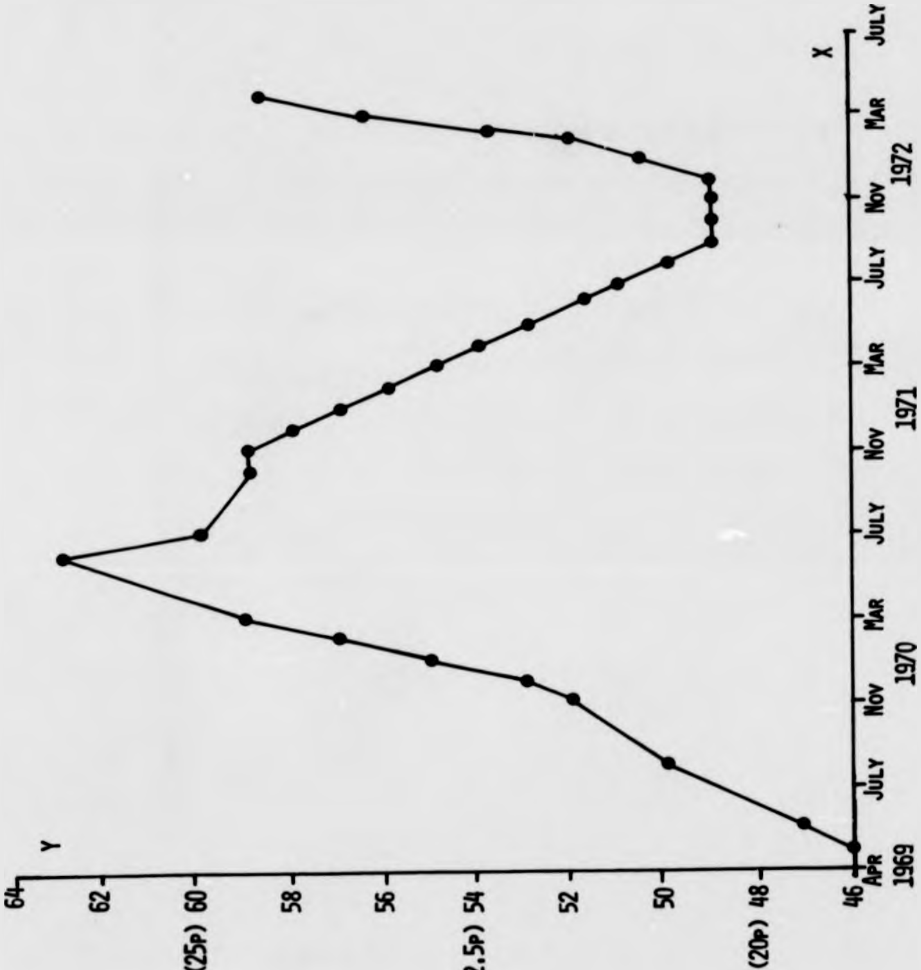

FIGURE 6

The pattern of price movements for Danish and Japanese frozen trout imports to the U.K. over the period: September 1967 - May 1973.

Y = Purchase price (p./lb.)

X = Month of purchase (increments of two months).

Price data refers to the mean monthly unit prices paid by Compass House Ltd. (C.I.F. Grimsby) for purchased lots of gutted and gilled trout into cold store. Data for Japanese trout (broken line) is not available subsequent to March, 1972.

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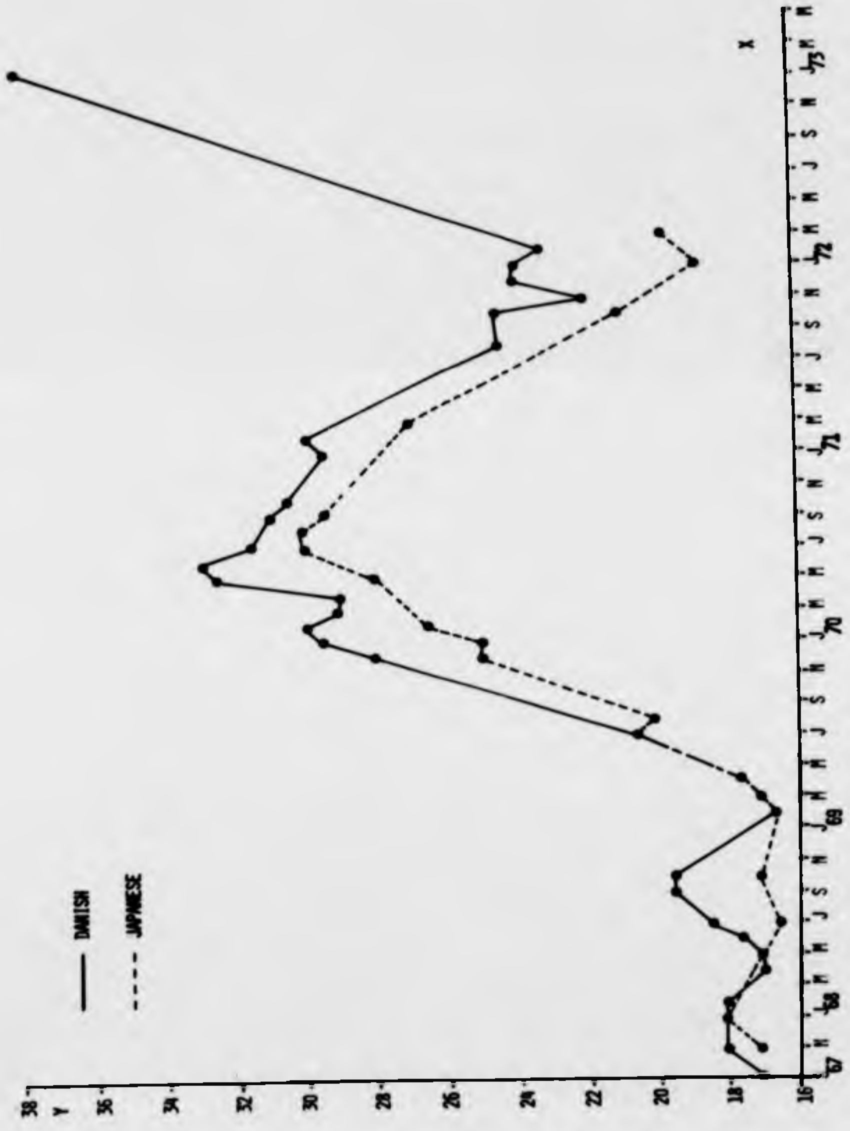

FIGURE 7

The pattern of price movements for frozen Japanese trout imports to the U.K. over the period July 1964 - May 1973.

Y = Purchase price (p./lb.)
X = Time of purchase (increments of 1 year)

Price data refers to the mean monthly unit prices paid by Peabody Ltd. (C.I.F. London) for purchased lots of gutted and gilled trout into cold store.

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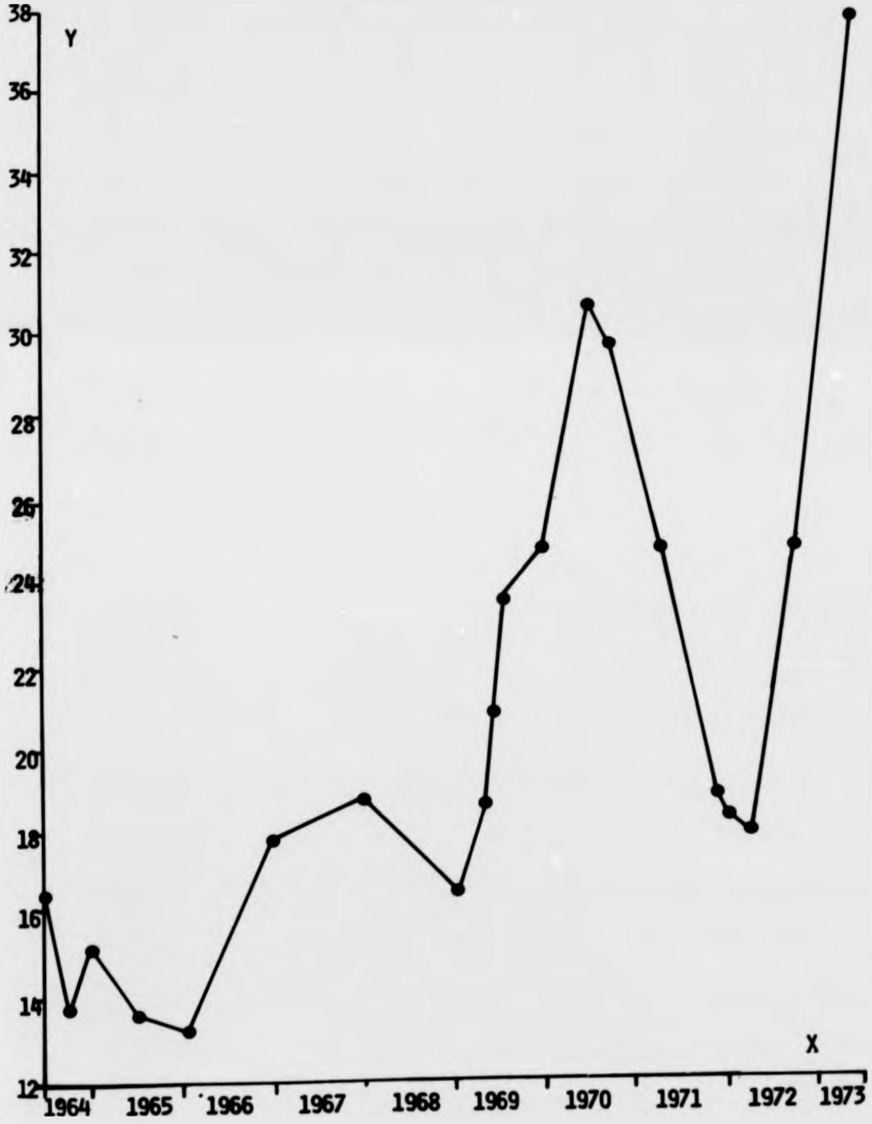

Sprats, Eels and Roe)

i) as real incomes have risen, so consumer expenditure on this group of fish has risen proportionally more

ii) the fact that quantities purchased have not shown such a great rise suggests that more of the higher priced fish in the group are being purchased.

Table 13

Income Elasticity of Fresh fat fish (excl. Herring)
Source: National Food Survey Committee

	1962	1965	1967	1969
Income elasticity of expenditure (+)	1.44	1.72	1.59	0.88
Income elasticity of quantity purchased (+)	0.60	1.73	1.14	0.47

(iii) Season

Certain traders claimed a small increase in demand during the winter months, particularly during Christmas and New Year. This is probably associated with the increased volume of catering trade at that time of the year.

(iv) Substitutes

The substitution possibilities and cross-elasticity of demand for farmed trout with wild Salmon and Sea trout in Norway has been described by Berge (1968). This refers to large trout (ca.1 kg.) with pink flesh which appear very similar to wild Grilse. Portion size trout occupy a different position in the market (smaller weight, catering sales, etc.) and are either eaten as the fish course to a meal or as a main course (whole).

Trout served as the fish course to a meal might be expected to exhibit cross-elasticities with Dover Sole, Scampi, Potted Shrimps, etc.

(v) Quality

(a) Appearance

There is a premium demand for freshness and U.K. producers of fresh trout may achieve a small price advantage, relative to Danish imports of fresh trout, on grounds of freshness.

Certain producers are producing trout with artificially pigmented flesh (pink - Chapter 7); it is possible that this may achieve a premium, particularly if delivered direct to hotels and retail outlets. Wholesale markets claim that the market as a whole is not educated to this and white flesh is still preferred.

(b) Source

Danish frozen trout usually achieves a premium of 1-2p./lb. over Japanese trout in the U.K. market. It is claimed that caterers can detect an inferior quality of Japanese trout.

(c) Hygiene

Human fatalities have recently occurred in Germany due to Botulism contracted from smoked trout contaminated by the toxin (Wenzel et al., 1971). This event was followed by the removal of trout from the inventories of Grand Metropolitan Hotels, Marks and Spencer, Sainsbury and Trust Houses Forte. This was not due to a fall in consumer demand: e.g. Findus claim that they took over Marks and Spencer's market by selling trout to retail stores adjacent to Marks and Spencer, and probably all caterers who removed trout from their inventories have subsequently restored it. Thus hygiene hazards can have a potent effect in limiting trade in trout by influencing wholesale demand. This possibility is assisted by the smallness of the market and relative unimportance of trout compared with other fishery lines for most frozen food and catering companies.

(d) Grading, Packaging

Weight class is a critical factor in trout sales and different markets require different weights (and often pay different prices). Thus accurate grading is required. Packaging is critical for retail sales and home freezer sales; it is of moderate importance for catering sales and unimportant for smoking.

(vi) Promotional Aspects

It is apparent that there is little active promotion of trout sales and what there is concentrates on the frozen and smoked retail market. Findus, who advertise trout (Fig. 8), claim that trout lines are retained only because they assist in promoting the image of the company as producing high quality frozen and fresh fish. It may be that increased promotion (e.g. brand, sales, advertising) could increase demand for trout products.

(vii) Price Movements

(a) Seasonal

It is claimed that there tends to be a seasonal price fluctuation for trout in the U.K. Thus importers tend to purchase trout in the Autumn and hold it in cold store in expectation of price rises over the winter period. These price rises are due to shortfalls in supply, notably when ponds freeze. During the winters 1970/71, 1971/2, and 1972/3, there have not been significant shortfalls since the winter

Fig. 8 Findus advertisement for trout

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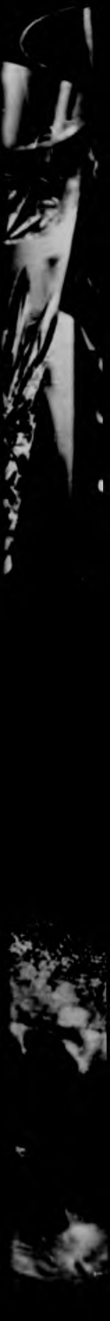

he Fishermen bring you the finest fish. Rainbow Trout.

indus know about fish. It's their special subject, and uality of their fish in all its forms is the proof. lus catch a wide range of fish, but they take special e in being able to offer you Rainbow Trout. Superb , and perhaps the tastiest of all freshwater fish. heir expertise ensures that the delicate flavour and te flesh of the trout are gently and wholly preserved. ere's an unusual method of preparing trout brings out its flavour to the full. It's a recipe from land and we've called it Haarlem Trout.

arlem Trout.

need: ½ pint of water; 1 bay leaf; nd pepper ; 2 packets of Findus ow Trout; 4 tablespoons frozen ntrated orange juice, defrosted; espoons lemon juice; 2 oz butter; espoons arrowroot; 1 heaped poon chopped parsley; ices of orange and lemon. *4 portions.*

the water to the boil in a large pan with the bay leaf, salt and r. Gently poach the trout in the water for about 15 minutes. Remove fish, transfer them to a warmed serving dish and keep hot. Remove the bay leaf from the liquor and add the orange and lemon juices. Melt the butter in a small pan, stir in the arrowroot and gradually add the stock and juice mixture. Bring to the boil stirring constantly until slightly thickened, add the parsley. Pour the sauce over the trout and garnish with orange and lemon slices.

y Findus take the Whole Plaice apart.

indus use a special process in the preparation of r Whole Plaice. The fish are cut open and skilfully ted. The fillets are then carefully folded back to inal shape, so, you buy the whole fish, its ur and nourishing protein completely retained.

Peeled Prawns. A Findus Speciality.

Another Findus speciality is prawns. They're peeled, so they're ready to be used in your cooking or perhaps eaten cold in prawn cocktail. A simple, but rather delicious variation is Californian Prawn Cocktail.

✽ **Californian Prawn Cocktail.** You'll need: ½ lb fresh prawns OR 2 packets Findus Peeled Prawns, 2 grapefruit, lettuce – shredded, 2 tbsp. mayonnaise, 2 teasp. tomato purée. *Makes 4 portions.*

Reserve a few whole prawns for garnishing, chop the rest. Cut washed grapefruit in halves, scoop out the flesh and drain off excess juice if the fruit is very juicy. Mix grapefruit flesh with the chopped prawns and shredded lettuce. Stir tomato-tinted mayonnaise into the mixture. Divide the cocktail between the grapefruit halves and garnish with prawns.

Continental Fish Dishes. Only from Findus.

Findus use firm-fleshed, young cod steaks, cut whole from the body of the fish, as the basis of their continental-style Fish Bake Bordelaise and Savoury Fish Fiesta. The full flavour of the fish is then brought out by a specially prepared sauce. Savoury Fish Fiesta, is made from tomatoes, red and green peppers, herbs, spices, and onions. It's new, quite delicious, and only from Findus.

Garnishing Fish Dishes.

Even the simplest of fish dishes can benefit from garnishing. And the simplest garnishes are often the most effective — sprigs of parsley, lemon wedges and slices of tomato. These are popular because they're quick and easy to prepare, but sometimes a special occasion or dish can call for more elaborate ones, such as croûtons, sliced gherkins or chopped dill.

Wine with Fish.

The drinking of a well-chilled white wine with fish is not a rule, but based on popular preference. Fish is a delicately flavoured food, and should not be overwhelmed by the taste of the wine that accompanies it. You can't go wrong with a light, dry Hock.

Findus. The Fishermen.

Good Fish Guide.

p you get the very best results from your fish the experts in the Findus Kitchen have prepared ish Guide. In it, they provide all you need to know oking and serving fish, with complete sections to dressings, garnishings, sauces, herbs, spices, nd even place settings. There are also over eighty from the countries of Europe. And it's yours by g a P.O./Cheque for just 10p to:

.N. Packing Services Ltd., 53 Pavilion Drive,
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The Fishermen.

temperatures have been relatively high, and importers have complained about the absence of any corresponding price effect (Smith, personal communication). Insufficient historical data is available to quantify the extent of this seasonal price fluctuation.

A seasonal pattern of trout sales on the Tokyo wholesale fish market has been described by Brown (1969). He claimed that there was some evidence of an inverse price/volume relationship for the years 1964 - 1966. Additional data collected by the author (Fig. 9) would tend to support this concept for the years 1967 - 1971. Unfortunately, such data does not exist for British markets.

(b) Wholesale Price Inflation

There had been little price movement for the 10 years preceding 1969. Between July 1969 and June 1970, wholesale cost prices for frozen trout escalated by ca. 60% (21p./lb. - 34p./lb.) before returning briefly to the previous level during the period October 1971 - April 1972 (Fig.6 & 7). They then rose to the present levels of ca. 38p./lb., and this pattern of fluctuation has occurred with fresh trout prices also (Fig. 5). The average C.I.F. prices for imports of fresh trout to the U.K. in 1967 - 1971 were 16p., 16p., 18p., 23p., and 23p./lb. respectively (derived from Table 7).

The large price rise in 1969/70 coincided with a European famine of trout and a large fall in Danish production and export (Table 14). This would appear to substantiate the claim of the industry that price movements in the U.K. are primarily a reflection of international changes in supply and one may assume a static demand . It is notable that the recent inflation of trout prices has been exceeded by the rate of price inflation

FIGURE 9

The yearly patterns of sales volumes and unit values for rainbow trout sold at Tokyo wholesale fish market over the period 1967 - 1971. Data modified after Hirayama (personal communication).

Y = Monthly volume of sales (tons)
Y^1 = Monthly unit value of sales (Yen/Kg.)
X = Month

A = Graph of the yearly pattern of unit value of sales
B = Graph of the yearly pattern of volume of sales

Each individual plot represents the mean value for the five years (1967 - 1971) of the average values recorded for that month.

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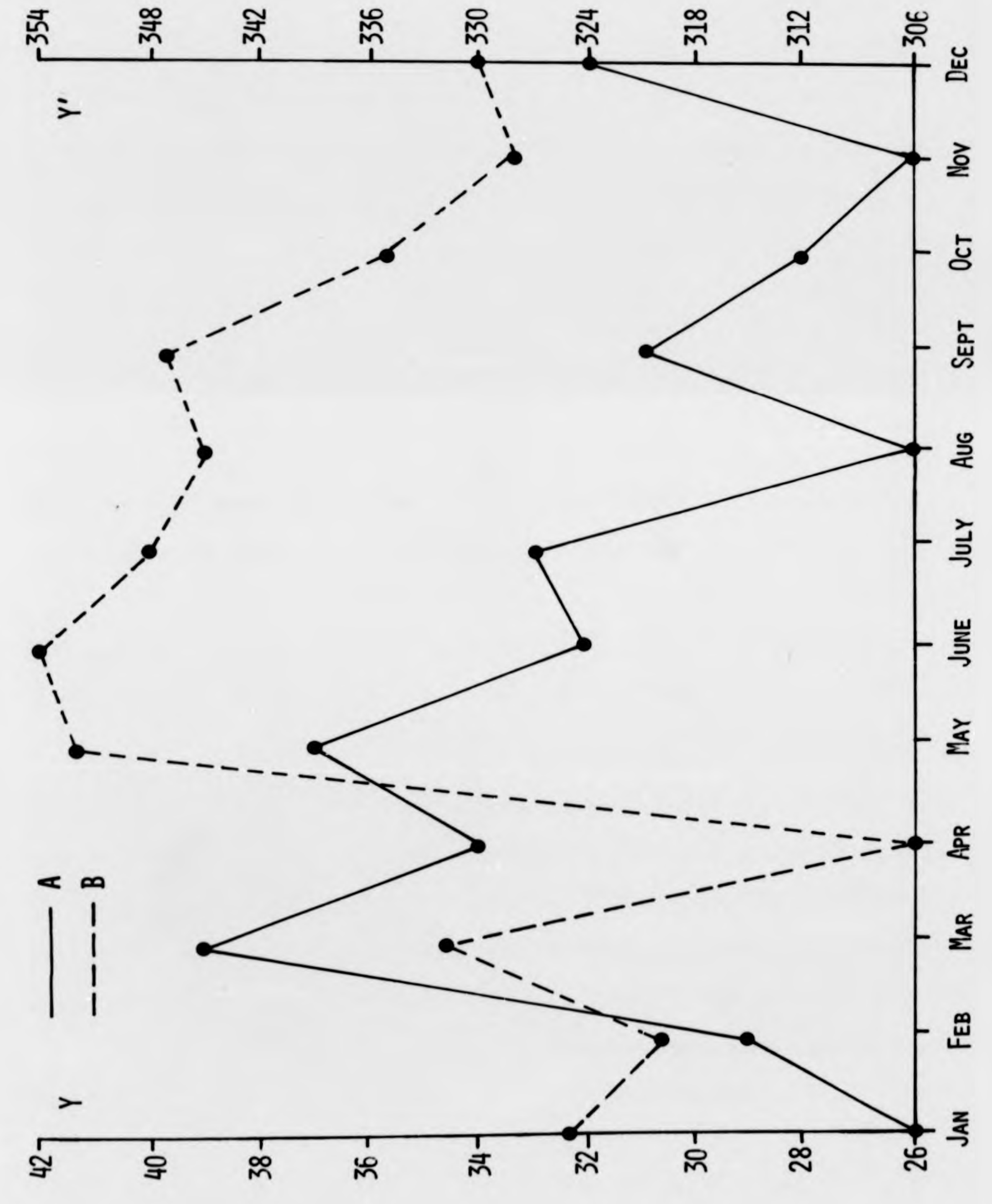


of some other fish in the U.K. (Chapter 2), including certain species, e.g. Cod which have not hitherto occupied a luxury market. Increasingly Trout is thus occupying price classes shared by fish which are not regarded as luxury items.

Table 14

Exports of farmed Rainbow Trout (alive, chilled and frozen) from Denmark during the years 1960 - 1971

Year	Exports (tonnes)	Value (£/tonne)
1960	5,946	361
1961	7,506	376
1962	7,680	392
1963	7,798	414
1964	8,225	421
1965	10,779	368
1966	10,099	436
1967	10,555	428
1968	12,121	416
1969	10,464	474
1970	8,539	575
1971	11,168	519

3.2.8.
INTERNATIONAL ASPECTS

(i) Europe

It is claimed by the major Billingsgate wholesaler of fresh trout that prices at that market tend to follow the prices achieved by Danish exporters in West Germany (Hallam, personal communication). In 1971, West German production of trout was ca. 6,000 tons (Nordsee Bremerhaven, personal communication) and imports totalled 5,602 tons of which 75% came from Denmark. West Germany had the largest home market for trout in 1971(Table 15) in Europe.

Table 15

Table of production, import and export data for trout in E.E.C. countries (as of 1973) for the year 1971
(Source: Foreign trade statistics, pers. comm., etc.)

Country	Home Production (tons)	Imports (tons)	Exports (tons)	Total market (tons)
West Germany	ca. 6,000	5,602	ca.0	ca. 11,600
France	ca.10,000	1,024	363*	ca. 10,600
Italy	ca. 10,000	46	1,058	ca. 9,000
Belgium and Luxembourg	ca. 0	2,612	32	ca. 2,600
Great Britain	> 200	1,916	5	>2,100
Holland	ca. 0	619	117	ca. 500
Ireland	127	ca. 0	46*	ca. 80
Denmark	> 11,168	ca. 0	11,168	ca. 0

N.B. (i) ca. 0 indicates values probably not exceeding 10 tons
(ii) * indicates a value corresponding to 1970 (1971 data unavailable).

The pattern in the E.E.C. countries has been generally of an expanding market, particularly in West Germany, France and Italy due to increased home production. Denmark remains the largest national exporter of trout in the world and has no home market. Since Denmark's accession to the E.E.C., tariff barriers on trout exports to other E.E.C. countries have been scheduled to fall, concurrently with a rise in the tariff barriers imposed on countries outside the E.E.C., e.g. Japan (Table 16).

Table 16

Schedule of changes in Tariff barriers imposed on trout imports to U.K. from Denmark and Japan

Date of change	Tariff on Danish trout imports to U.K. (%)	Tariff on Japanese trout imports to U.K. (%)
1st Jan., 1973	8	10.0
" " 1974	6	10.8
" " 1975	4	11.2
" " 1976	2	11.6
" July, 1977	0	12.0

Up to 31st December, 1972, an E.F.T.A. tariff of 10% had been levied on exports of Danish (and Japanese) trout to the U.K. The competitiveness of imported Danish relative to home-produced trout is likely to be enhanced by this tariff reduction.

It might be considered that accession to the E.E.C. would increase the attractiveness to the U.K. of exporting to other community nations. Such export sales would require to be competitive with the importing countries' home production and/or other imports (e.g. Danish).

(ii) World (Excluding Europe)

The U.S.A. and Japan are the two largest trout markets outside Europe. Both markets are supplied largely by home production. Japan's production for 1969 was estimated to be ca. 13,400 tons (MacKenzie, personal communication). U.S. commercial production in 1969 was ca. 5,800 tons (Dillon, 1969) but had risen to ca. 15,000 tons by 1972 (Pyle, personal communication.).

Table 17

Volume of Rainbow trout exports from Japan (1968 - 1970) and list of main destinations

(Source: Japanese Ministry of Agriculture and Forestry)

Destination (country)	Volume of exports (tons) 1968	1969	1970
U.S.A.	1,385	991	1,118
U.K.	564	680	680
West Germany	51	653	786
Canada	247	168	148
Belgium	186	231	112
Others	130	154	140
TOTAL	2,563	2,877	2,984

Denmark had a considerable export market in the U.S.A. until U.S. legislation was drafted prohibiting the import of trout without certification of freedom from Whirling disease parasites, causing a fall in Danish exports to the U.S.A. from 706 tons in 1968 to 7 tons in 1969. It does not appear (Table 17)that the Japanese exporters made any attempt to exploit this situation. The U.K. had remained the second largest export country for Japanese trout until overtaken by West Germany in 1970, but this export trade fell to 80 tons in 1971 and more Japanese trout was sold in the U.S.A. Over this period, Japanese trout imports to the E.E.C. bore a tariff of 13.6% which was reduced to 12% in September, 1971. The U.K. tariff is rising from 10% to 12% over the period 1973 - 1977 (Table 16); however, this is likely to have an insignificant effect since Japanese trout undercut Danish trout during 1968 -

1972 (Danish prices were up to 16% above Japanese, Fig. 6). Danish exports are therefore somewhat unpredictable. One Scottish company (Gateway West Argyll Ltd.) has started to market small volumes of frozen trout in the U.S.A. and Canada (via Cloustons of Montreal). The distance of the U.S. eastern seaboard from the major trout producing areas (Idaho, etc.) appears to make this a feasible market area.

3.3 Conclusions

Before the current decade, the world market for trout had been a rather stable oligopoly, supplied mainly by Denmark and home production. Although market characteristics varied for individual countries, essentially the trade was fairly static and was a luxury trade largely centred on high-class catering establishments.

Recently many countries have increased the scale of production for the table and, to a lesser extent, for restocking. A similar pattern is beginning to emerge in the U.K. Trout sales in the U.K. have hitherto been small relative to those of other fish, and not obviously related to price. There is some evidence of an increase in the U.K. consumption of higher-priced fish. It is likely that there is scope for an induced demand for trout which may be assisted by e.g. promotional aspects. If this is the case, it might well be more easy to influence the frozen retail market than the more traditional fresh and frozen catering markets or fresh retail markets (e.g. by means of the expanding U.K. home freezer market). Attempts are already being made to segment the market (e.g. in Danish exports) by increasing production of various product presentations, brand-packaging, etc.

Probably the two main factors which are likely to act in determining U.K. sales of trout in the near future are:

i) the availability of trout, since other European countries have a higher consumption per capita than the U.K. and might reduce the exports to the U.K. from Denmark and Japan. However, the increasing home production might minimize this problem should it occur; the rate of increase in home production has been estimated at 20% per annum for the next five years by one trout feeds producer (Stratford, personal communication).

ii) the ease with which trout is able to penetrate the retail market. The catering market is traditional and unlikely to experience an upswing in demand. Increasingly, however, trout could be retailed to the housewife through home-freezer sales and via freezer cabinets in supermarkets, delicatessens, etc. In this market, it would be in direct competition with, e.g. Scampi, shrimps, Dover Soles, Halibut steaks, etc. In this connection trout sales might suffer because of the problems associated with its preparation for the table. It is likely that presentation of the product (packaging, filleting, provision of recipes, etc.) would be a significant factor in the success of any such sales. Future price movements are likely to render trout inexpensive compared to its substitutes and this might adversely affect its luxury connotations and thus sales volume. However, it is probable that any such tendency would not be perceived in the market where it would be most likely to occur, i.e. in the catering trade where the consumer pays the highest price for trout (since the likelihood would be that the caterer would merely obtain a greater margin and the consumer would pay the same price). In the retail market, price competitiveness would probably become an important factor in stimulating demand. The fact that trout sales have been relatively inelastic to price changes hitherto is probably irrelevant, since it is unlikely that the catering trade would behave similarly to a retail frozen trade, i.e. a novel market. It might even be the case that in the event of large trout supplies becoming available at a relatively low price, sales might increase markedly and retail outlets multiply as occurred with the sales of Broiler chickens in the U.K.

Increasing volumes of farmed trout in the U.S.A. are being stocked in Fish-Out ponds ('Put and Take'; 'U-fish') to encourage the purchase of fish which are fished for by the buyer (who usually leases the rod in addition). These operations are regarded as highly popular and profitable and would seem a rational extension of current fish farming activities in the U.K. It is probable that such systems would be more popular in England than in Scotland due to the decreased availability and tradition of skilled trout fishing there and the larger urban populations etc. In any case, the increased interest in and consumer surplus available for recreational activities are likely to provide an increase in demand for trout for stocking in the future.

CHAPTER 4

BIOLOGICAL REQUIREMENTS OF SALMONIDS

4.1 Introduction

In planning a suitable system for the culture of animals in an environment which is unnatural compared to the wild state, it is important to examine their normal biological characteristics and requirements. With Rainbow trout, for example, it is likely that evolutionary mechanisms will have brought about the emergence of many characters whose net effect tends to enhance the growth and well-being of natural populations. However, there may be a variety of diverse environmental factors in the natural state tending to oppose the full theoretical potential production of trout. Thus it is likely that a culture system which aims to maximize productivity in an artificial environment, will wish to achieve this mainly by reduction or elimination of those factors which are limiting in the natural state. The particular environmental requirements of Rainbow trout will be examined, although it must be emphasized that these change over the life cycle of the fish and the various factors are in a continuous state of dynamic interaction.

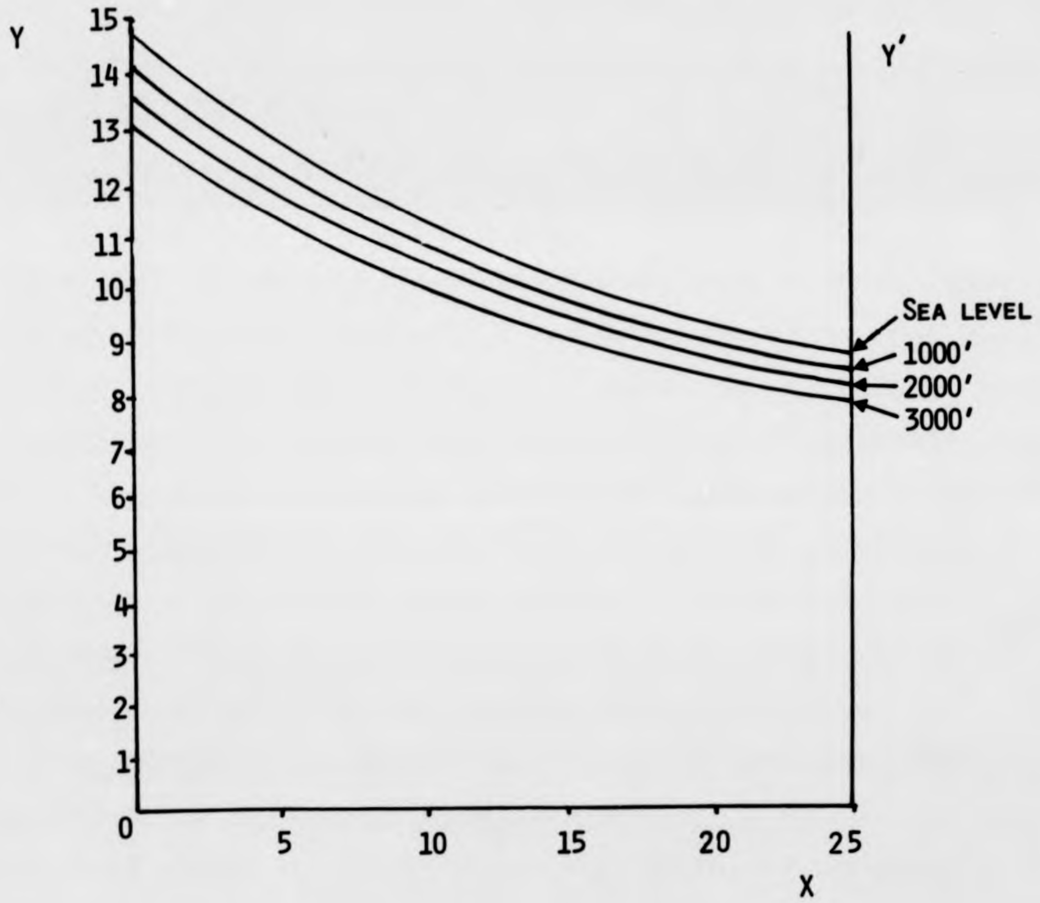
4.2 Oxygen Requirements

Oxygen generally enters a body of water from the atmosphere, and thus much ground water is relatively deficient in oxygen until the watercourse has been in contact with air for sufficient time to enable the oxygen gradient to equilibriate. The point of equilibrium depends on several factors, including the atmospheric pressure. Thus altitude, which affects atmospheric pressure, will also influence the capacity of water to absorb oxygen. Figure 10 demonstrates the extent to which

FIGURE 10

Diagram to indicate the relationship between water temperature, altitude and the content of dissolved oxygen in fully saturated freshwater.

Y = Dissolved oxygen content at saturation (p.p.m.)
Y^1= Altitude above sea-level (feet).
X = Ambient water temperature (°C).


Y
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
5
10
15
20
25
X
Y′
Sea level
1000′
2000′
3000′

the oxygen saturation value decreases with increased temperature and altitude. At sea-level, water is fully saturated with oxygen at 14.62 p.p.m. when at 0°C; this value falls to 8.38 p.p.m. at 25°C. These relationships are also affected by the presence of dissolved substances in water. Thus, by virtue of its dissolved salts, seawater (20,000 p.p.m. Chlorides) can carry less oxygen than fresh water - 11.32 p.p.m. at 0°C, and 6.74 p.p.m. at 25°C at an atmospheric pressure of 760 mm.Hg. and pO_2 of 160 mm.Hg.

Organic matter in water may cause oxygen to leave solution and thus exert a 'Biochemical oxygen demand' (B.O.D.). The presence of certain types of pollution (e.g. silage liquor) in a watercourse, may have such a large B.O.D. as to remove all dissolved oxygen from the water. Similarly, prolonged periods of darkness (e.g. during long winter nights, especially when there is a thick ice-cover) will limit photosynthesis while aquatic plants will continue to respire, with a consequent reduction in dissolved oxygen levels. Turbulent water conditions, however, are likely to have the opposite effect and to cause the water to tend towards supersaturation.

According to Schäperclaus (1961), the following low oxygen levels act on Salmonids as described:

5.0 - 5.5 p.p.m. is critical at high levels of activity
4 p.p.m. produces difficulty in respiration
3 p.p.m. causes death over an extended period of time
1.5 - 2.0 p.p.m. is lethal in a short time.

Modifying data derived from Downing and Merkens (1957) to give their experimental results in terms of the minimum concentrations of dissolved oxygen (p.p.m.) at which all individual Rainbow trout survived at three different temperatures, the effect of altering the duration of the test may be seen, as follows:-

Duration	Temperature of water 10°C	 16°C	 20°C
3½ hours	1.7 p.p.m. O_2	1.9 p.p.m. O_2	2.2 p.p.m. O_2
3½ days	1.9 p.p.m. O_2	3.0 p.p.m. O_2	2.6 p.p.m. O_2
7 days	-	3.8 p.p.m. O_2	2.7 p.p.m. O_2

Davis (1953) probably provides an adequate summary in advising that trout should not be held for extended periods in water containing less than 5.0 p.p.m. oxygen.

It is obvious from the foregoing that atmospheric conditions etc. may act on the physico-chemical characteristics of a body of water in such a way as to prohibit there being sufficient dissolved oxygen in the water for fish health to be maintained (i.e. less than ca. 5 p.p.m.). Fish themselves are continually removing oxygen from solution and, particularly under conditions of heavy stocking, this may reduce an adequate oxygen level to a dangerously low one. Thus it is pertinent to consider those factors which affect oxygen uptake rate in fish.

Wells (1935) and Beamish (1964) reported the occurrence of seasonal changes in the oxygen consumption in different species of fish. Maximal oxygen consumption appeared to coincide with the point of reproduction although this would be unlikely to affect the activities of the fish culturist who generally maintains only a small number, if any, of brood fish at a low density.

Beamish and Dickie (1967) described how the oxygen uptake of fish may vary widely at a given level of activity and water temperature. With an increase in swimming speed and water temperature, the rate of oxygen consumption also rose. For active fish, the rate of oxygen uptake decreased as a consequence of a reduction in ambient oxygen levels. It appears that, in the presence of carbon dioxide, a reduced affinity of haemoglobin for oxygen causes a lowered oxygen consumption. Thus Basu (1959) proposed that the logarithm of active oxygen consumption decreased linearly with increase in pCO_2.

According to Frost and Brown (1967), at a temperature of 16.5°C, Rainbow trout survive at least 24 hours with only 2 p.p.m. O_2 in the absence of CO_2, but most of them die in less than one hour when 15 p.p.m. of CO_2 is present. In a brief review of factors affecting fish oxygen consumption, Liao (1971) mentioned water temperature, activity level, sex and season, ambient oxygen level, fish species and size, and catabolic products. He considered that fish activity level varies with fish size, water temperature, ambient oxygen concentration, and (in the fish farming situation) the three factors of loading density, pond hydraulic pattern and hatchery operating procedure. In practice, he considered that, for Rainbow trout, oxygen uptake was mainly dependent upon water temperature, activity level and the size of fish, and that unit oxygen uptake rate was proportional to the water temperature and inversely proportional to the fish size. Various authors, including Liao, have attempted to estimate the water requirements of Salmonids by calculations based directly or indirectly on their oxygen uptake rates. A survey of these attempts is undertaken in Chapter 6.

Water temperature will now be discussed in more detail since its importance is related both to the saturation value of water for oxygen and also to the increase in metabolic rate of aquatic animals consequent upon a rise in temperature; thus Leitritz (1960) reported oxygen consumptions for yearling Rainbow trout of 3 c.c./hour at 7.2°C., and 12 c.c./hour at 20°C.

4.3 Temperature Effects

Fish are poikilotherms in that their body temperature adapts to that of their environment. Rainbow trout do not thrive for prolonged periods at temperatures above 21°C, although they can withstand higher temperatures (*ca.* 30°C) for a short time (Schäperclaus, *loc.cit.*).It is not absolutely clear whether this effect is due to the relative oxygen scarcity at higher temperatures, or some other change, or a combined effect. Provided there is sufficient oxygen, Rainbow trout will survive in water underneath ice-cover at temperatures down to 0°C. Garside and Tait (1958) have reported a preferred temperature for Rainbow trout of 13°C.

There has been considerable debate concerning the optimum temperatures for rapid growth. Working with Brown trout, Brown (1946) found that optimum growth occurred within two different temperature ranges: 7-9°C and 16-19°C. She claimed that optimum temperatures for rapid growth are those at which appetite is high and maintenance requirements relatively low, whereas minimum growth occurs at the intermediate temperatures where maintenance requirements are high because the fish are most active. She points out that the maintenance requirement (expressed as weight of food absorbed per unit weight of fish, when the fish's weight is constant) increases with rise in temperature; thus the effect of a rise in temperature is to increase the amount of food required by the trout to maintain its body weight. Other workers have been unable to repeat Brown's findings.

Swift (1961) postulated only one optimum of 12°C, similar to Brown's lower temperature. Baldwin (1956) found the optimum temperature for growth of Brook trout (*Salvelinus fontinalis*) was 13°C. Atherton and Aitken (1970) have criticized Brown's interpretation of her data and have claimed that approximately 12°C is the optimum temperature for growth when Rainbow trout are fed a low fat diet. Feeding a high fat diet resulted in fish at 16°C showing an improved growth rate over fish kept at 12°C. Furthermore, they postulate that at 16°C Rainbow trout excreted very little ingested nitrogen when fed high levels of dietary fat; thus more nitrogen was available for protein, and hence growth.

It is appropriate at this stage to consider the possibility that the circumstances of a particular fish (e.g. activity, size, sex) may be associated with different temperature effects as different energy requirements are involved.

Phillips (1969) in his review of energy utilisation of fish, distinguished between basal metabolism, growth, reproduction and physical activity. The terminology for different levels of metabolic rate and associated activity levels (after Brett, 1972) may be appreciated in the context of fish culture as follows:

Metabolic Rate:	Basal; Standard	Routine; Intermediate; Transport	Active
Activity Level:	Complete rest (zero activity)	Normal activity without stress	Maximum sustained activity
Feeding, and growth rate	Post-absorptive state	Daily feeding; growing	Seizing, Chasing etc.

The energy required for basal metabolism in fish (i.e. the 'standard metabolism' of fish physiologists, which has been defined by Fry (1971) and Brett(loc.cit.): 'that which occurs at zero activity by extrapolation') has been defined as the approximate equivalent to basal metabolism in man (Fry and Hart, 1948). Any increment above this level indicates an increase in metabolic rate, oxygen consumption being considered a valid measure of energy requirement of fish since an increase in metabolic rate causes an increase in oxygen consumption, 'provided the fish is aerobic'(Morgan, personal communication). Phillips considered the effect of water temperature on energy required for both standard metabolism and physical activity (loc. cit. measured by swimming speed). Brett(1964) showed that at temperatures up to 15°C, active metabolic rates were 10-12 times the standard level for Sockeye Salmon (Oncorhynchus nerka), but above 15°C the ratio dropped and was only four times the standard rate for Salmon acclimatized to 24°C. 'Burst' activity appears to have somewhat differing characteristics (Blaxter, 1968) but, since this is unlikely to be of much significance to the fish farmer, such effect will be ignored.

4.4 pH, Hardness and Ammonia

The pH value of a water is a measure of the acidity (below 7) or alkalinity (above 7) and is defined as the reciprocal of the logarithm of the Hydrogen ion concentration. Schäperclaus (loc.cit.)has defined the limits of the pH range for trout as 4.5 - 9.2.

Acidic water is found in regions deficient in Calcium associated with igneous rock parent material. Many upland parts of Scotland are covered by peat moors, marsh and heathland which impart acidity, and a low pH, to water running off them.

'Hard' waters contain large quantities of Calcium Carbonate and Bicarbonate. Usually a water which is hard is also alkaline because the bicarbonates tend to buffer the effects of acidic substances such as dissolved Carbon Dioxide (which will form a weak acid in solution but, in the presence of bicarbonate ion, any tendency to a lowered pH will be resisted). A 'soft' water is not necessarily acid, although it will have a very diminished ability to resist any increase in hydrogen ion concentration. Frost and Brown (loc. cit.) distinguished five main differences between waters from lime-bearing and non-calcareous rocks:

(1) amount of Calcium
(2) amount of carbonates and bicarbonates in solution
(3) total amount of dissolved salts
(4) pH
(5) amounts of organic matter in solution

These water characteristics, and their inter-relationships, reflect, to a large extent, the ground from which the water is derived or through which it has passed. Since the pH value of a water indicates the balance of acidic and alkaline ions, it is to be expected that the pH will have an influence on the chemical nature of many substances dissolved in the water.

Ammoniacal substances are produced as excretory products by Salmonid fish and it seems likely that, although Urea will be inert and unlikely to act in a deleterious manner to fish, the pH of the water will partly determine the degree of dissociation of Ammonia, of which the unionised component is likely to be harmful (Wuhrmann and Woker, 1948).

$$NH_3 + H_2O \overset{(i)}{\rightleftharpoons} NH_4OH \overset{(ii)}{\rightleftharpoons} NH_4^+ + OH^-$$

(TOXIC FORM) (NON-TOXIC FORM)

Thus in the above diagram, equation (ii) is pH dependent. Burrows(1964) demonstrated the patterns of excretion among Chinook Salmon fingerlings (Oncorhynchus tshawytscha) at different stocking levels, and suggested that concentrations of unionized Ammonia as low as 0.006 p.p.m. in continuous exposure for 6 weeks can produce extensive hyperplasia of the gill epithelium. (This effect was not discovered with Urea). He demonstrated that prolonged but intermittent exposure to unionized Ammonia results in reduced growth rate and physical stamina and also predisposes to bacterial gill disease. Downing and Merkins(loc.cit.)& Merkins and Downing (1957) demonstrated that the lethal nature of unionized Ammonia increased with a reduction in dissolved Oxygen. More recently, Smith (1972) has demonstrated that "as long as Oxygen levels were maintained at 5.0 p.p.m. or more, growth of trout was not significantly reduced until average total Ammonia concentrations reached 1.6 p.p.m. (0.033 p.p.m. unionized Ammonia) and only then after continuous exposure for at least six months". The disparity with Burrows' figures could be due to an intraspecific difference in resistance to Ammonia, or to low Oxygen tensions predisposing Burrows' fish to Ammonia toxicity, or to both factors. In his paper, Burrows (loc.cit)presented a table listing the percentages of unionized Ammonia contained in Ammonium hydroxide solution at three temperatures and over the pH range 7.0 - 9.5. The figures given (used also by Smith, loc.

cit.) have recently been criticized by Trussell (1972) who has presented alternative data over the pH range 6.5 - 9.0 and temperature range 5°C - 25°C. The latter data propose that, e.g. at pH 7.5 and 10°C, the percentage unionized Ammonia is 0.59 (whereas Burrows had suggested a value of 1.10%). Using the data of Trussell one may then restate Smith' - [illegible] "growth of trout was not significantly reduced until average Ammonia concentrations reached 1.6 p.p.m. (0.017 p.p.m. unionized Ammonia)", rather than the figure of 0.033 p.p.m. unionized Ammonia given in his paper.

Lloyd and Herbert (1960) have demonstrated that the free Carbon dioxide in the water can cause a decrease in the pH, and hence the amount of unionized Ammonia, at the gills. Thus the toxicity of Ammonia to Salmonid fish appears to be influenced by pH, temperature, dissolved Oxygen concentration and free Carbon dioxide in the water. Thus one may conclude by emphasizing the importance of monitoring Ammonia levels, particularly under conditions of heavy stocking, alkaline water and high temperature.

Scheffer and Marriage (1969) believe that "Hard water (50 - 250 p.p.m. dissolved solids or more) produces trout more economically than soft water - management problems are fewer". This is presumably an expression of the commonly held belief among trout culturists that fluctuations in the physico-chemical environment of the fish are likely to be stressful and thus water with an enhanced buffering capacity is likely to be beneficial. Although rigorous scientific work on this problem is lacking, the experience of many trout farmers who add Lime (Calcium Carbonate) to their inflows under certain conditions (e.g. during a spate) and allege that this prevents losses, cannot be ignored. It would seem probable that fish are able to acclimatize to the particular physicochemical regime of a water (to which they may to some extent have been selected). Thus any means of stabilizing this regime may serve to reduce stress and increase productivity among the population. Although various authors (for example Rasmussen, 1968) have recommended particular liming regimes, in practice those trout farmers who add Lime to their inflow, do so until the pH has been restored to its usual mean value.

This latter practice presupposes that a regular system of recording certain physicochemical parameters of the water is adopted by the trout culturist. Thus, if (at least) daily records of temperature, dissolved Oxygen and pH are maintained, it may be possible to arrive at an approximate, if empirical, guide to the optimal pattern of environment for fish productivity, given the physical lay-out of the farm. Consequent upon this, the farmer may then be able to identify particular operating procedures best suited to achieve this optimal environment under changing conditions. These procedures may include:

(a) changing stocking density
(b) changing water flows
(c) liming the water
(d) artificial aeration
(e) changing feeding rate
(f) changing cleaning procedures etc.

The problem of achieving an optimal environment is in the nature of a non-operational objective since there is, in many cases, insufficient biological information to identify either the components of optimality or adequate means of measuring them under what are often rapidly changing conditions. Furthermore, it is obvious from the foregoing that the means of altering the environment are often somewhat limited. Finally, the factors considered thus far are themselves generally in a state of dynamic interaction and thus any proposed modification to one factor must take into account the effects on the system as a whole (e.g. attempts to reduce the acidity of water should be undertaken in the knowledge that a more alkaline environment is likely to contain more unionized Ammonia).

4.5 Other Physico-chemical Factors

4.5.1 Dissolved Gases

Since the absorption capacity of water is greater for certain gases than it is for Oxygen, low dissolved Oxygen content may not be the only problem associated with the gaseous content of the water. Carbon dioxide is absorbed preferentially to Oxygen and low Oxygen content is often associated with high Carbon dioxide levels.

Water, particularly when derived from certain rock strata by wells or artesian bores, may have high levels of dissolved Nitrogen and Hydrogen Sulphide. The former, like Carbon dioxide, may displace Oxygen from solution. The latter is toxic to trout *per se*. In practice these gases may be removed with comparative ease by artificial aeration of the water entering the trout farm.

4.5.2 Other Solutes

Certain metallic cations may also be of significance in intensive trout culture. Under conditions of Oxygen shortage in particular, Iron and Manganese may be dissolved as bicarbonates and can form a colloidal precipitate of Iron and Manganese Hydroxides on the gills; this can also be a problem during egg incubation. However, it seems likely that Trout have requirements for certain trace elements (see Ch. 7 under 'Nutrient requirements'). It is probable that these will be provided in a commercially prepared diet. It could be that problems may arise when such elements (or non-essential elements) are present in unusually high concentrations in a particular watershed. Thus one trout farm (Muller, personal communication) with unusually high levels of Zinc ore, claimed that increased productivity of trout obtained when Zinc supplement was eliminated from the ration. There is insufficient biological information available on some of these aspects although Lloyd (1965) has demonstrated the effects of Zinc and Copper salts on trout and how the toxicity of certain cations to trout (notably Copper) may be influenced by changes in environmental variables which he listed as Calcium content, temperature, dissolved Oxygen, and activity rate, e.g. Copper and Zinc toxicity to trout is exacerbated in soft waters.

4.5.3 Particulate Matter

The presence of much particulate matter in water may be deleterious to fish health by mechanical irritation, particularly of the gill surfaces, which predisposes to disease processes. If organic, such material is also likely to remove Oxygen from solution by virtue of its B.O.D. Such materials in suspension may also bring about mechanical blockage of inlet pipes, screens and filters etc.

4.6 Biological Requirements of Trout Eggs

The biological requirements for incubation and hatching have been documented by various authors, including Schäperclaus (loc.cit.)& Rasmussen (1968). It would appear that the optimum temperature range is 8°C - 13°C, and that the water should contain at least 7 p.p.m. of dissolved Oxygen. Ferric Bicarbonate, if present in the water, is likely to precipitate out as the hydroxide on the alkaline surface of the germ and eggs which causes irritation and asphyxiation; such waters are thus unsuitable for egg incubation, as are those which contain much suspended material (unless this can first be removed by a filtration process). Apart from the above considerations, the required factors for egg incubation are similar to those required for the rearing of alevins and growing trout.

Mechanical disturbance or movement of trout eggs before the process of 'eyeing' occurs (when the embryonic eye first becomes evident), is likely to result in severe mortalities unless it takes place during the initial 20 - 40 hours after the eggs are stripped from the brood fish. Moreover, any eggs which die soon become the focus of fungal and bacterial multiplication. This process will generally result in the infection of adjacent eggs unless it is regularly checked by

(a) daily removal of dead eggs or

(b) daily disinfection with an antifungal agent.

4.7 Salinity Effects

Since those Salmonids cultured for food consumption are anadromous (i.e. live for part of their life cycle in the sea but need to return to fresh water to breed) in their native range, it is not surprising that attempts have been made to culture them in a salt water environment since the last century (Jensen, 1962). The experiments have met with varying success and important factors in the success rate appear to include the relations between salinity and age (or perhaps weight) at acclimatisation, acclimatisation rate, temperature, etc. Parry (1960), as cited by Conte (1969), investigating the development of salinity tolerance in juvenile Atlantic Salmon, Brown trout and Rainbow trout, showed that young fish were not completely homoiosmotic in full strength sea water and that osmoregulation in different salinities was dependent upon the size and age of the fish as well as upon the species. Holliday (1969) has reviewed some of the biological factors which he considered to have important economic implications to the fish culturist. He indicates that activity levels are often lower in low salinities and, since energy expenditure is thus less, ability to survive and achieve rapid growth rates may therefore be increased. Various workers have demonstrated that salinity tolerance among Salmonids is first evident to a small degree with eggs and thereafter increases with age. It is commonly believed by Norwegian workers that, for Rainbow trout, fish exceeding a unit weight of <u>ca</u>. 100 gm. are capable of being moved from fresh water into full strength sea water (<u>ca</u>. 34 ^{o}/oo salinity) without prior acclimatisation, provided that the water temperature is greater than <u>ca</u>. 6^{o}C.

The main factors involved in sea water culture of Rainbow trout (as occurring in Norway) comprise enhanced water availability and elevated temperature relative to fresh water sources. However, it has been postulated that salt water culture of Rainbow trout confers certain advantages over fresh water (at the same temperature) in terms of growth rates, feed conversion efficiency, etc. Although the evidence is as yet not clear-cut, such a phenomenon has been demonstrated in other marine species (for example: Kinne, 1960). Culture of fish in an environment of isosmotic salinity may confer beneficial effects which derive at least as much from the assistance that their specific gravity gives to swimming activity, as to the saving in energy by reducing the osmotic and ionic effects (Holliday, loc.cit.). It seems likely that current work will demonstrate particular advantages in growth rate accruing from culture of Rainbow trout at salinities below that of full strength sea water but considerably greater than fresh water (McLeod, personal communication). It does not necessarily follow that, at a suitable salt water site, these advantages will always be sufficiently attractive to justify the incremental investment required to achieve the required degree of salinity control.

It is possible that the comparative stability of the physical and chemical characteristics of sea water at full strength may be such as to render it a more attractive medium than fresh water under many circumstances. The solubility of Oxygen in sea water is less than that in fresh water, being 8.08 ml./l. at 0°C and 4.95 ml./l. at 25°C (Nicol, 1960). Although the Calcium content is 0.4 p.p.m., the total salts comprise 343 p.p.m., at 34 °/oo salinity (19 °/oo Chlorinity) with a pH range of 8.0 - 8.4, but on average 8.1 (Nicol, loc.cit.) Sea water has therefore considerable buffering power to compensate for the reduced Oxygen capacity from the cultural standpoint. The physico-chemical factors of the environment in general fluctuate over a wider range in fresh water than in full-strength sea water. The latter may therefore be the culture medium of choice for fish exceeding 100 gm. in unit weight (all other things being equal) simply on account of the reduced physiological stress afforded by the more stable sea water environment. It is likely, however, that the possibilities of providing a relatively stable fresh water environment by means of pumping from a large body of fresh water, utilising filtration and recirculation devices, utilising constant temperature warm water effluents, addition of buffering agents etc. will, under certain circumstances reduce the stress factor to a level equal to or less than that attained by salt water culture; the criterion of choice must in such instances be the value of the added productivity which may be achieved in relation to the incremental cost of achieving it.

4.8 Summary

The environmental factors which influence the growth and well-being of trout are discussed. Of particular importance is the content of dissolved Oxygen in the water, which is influenced by other factors notably temperature. It is likely that stability of the physical and chemical characteristics of the water supply is important to the culturist. This discussion assumes an adequate plane of nutrition; nutrient requirements are considered in Chapter 7.

CHAPTER 5

TECHNOLOGICAL SYSTEMS FOR TROUT CULTURE

5.1 Introduction

There is extreme variation in the detailed designs of the various husbandry systems feasible for trout culture. However, there are well recognised systems which have become popular, and represent a satisfactory compromise between economic and biological considerations under particular circumstances. Five criteria were established by Burrows and Chenoweth (1955) to compare the efficiencies of different systems, namely (a) Carrying capacity, (b) Disease inhibition, (c) Food distribution, (d) Cleaning efficiency, (e) Viability. Most trout culturists operating for the table market aim to maximize their sales within the constraints on labour, finance, site conditions, etc., and thus regard capital and operating costs as significant criteria of choice between different systems. Rearing systems are usually divided functionally and structurally into Hatchery systems, Early-rearing systems and On-growing systems, and will be described and compared under these headings. (Fig.11).

5.2 Hatchery systems

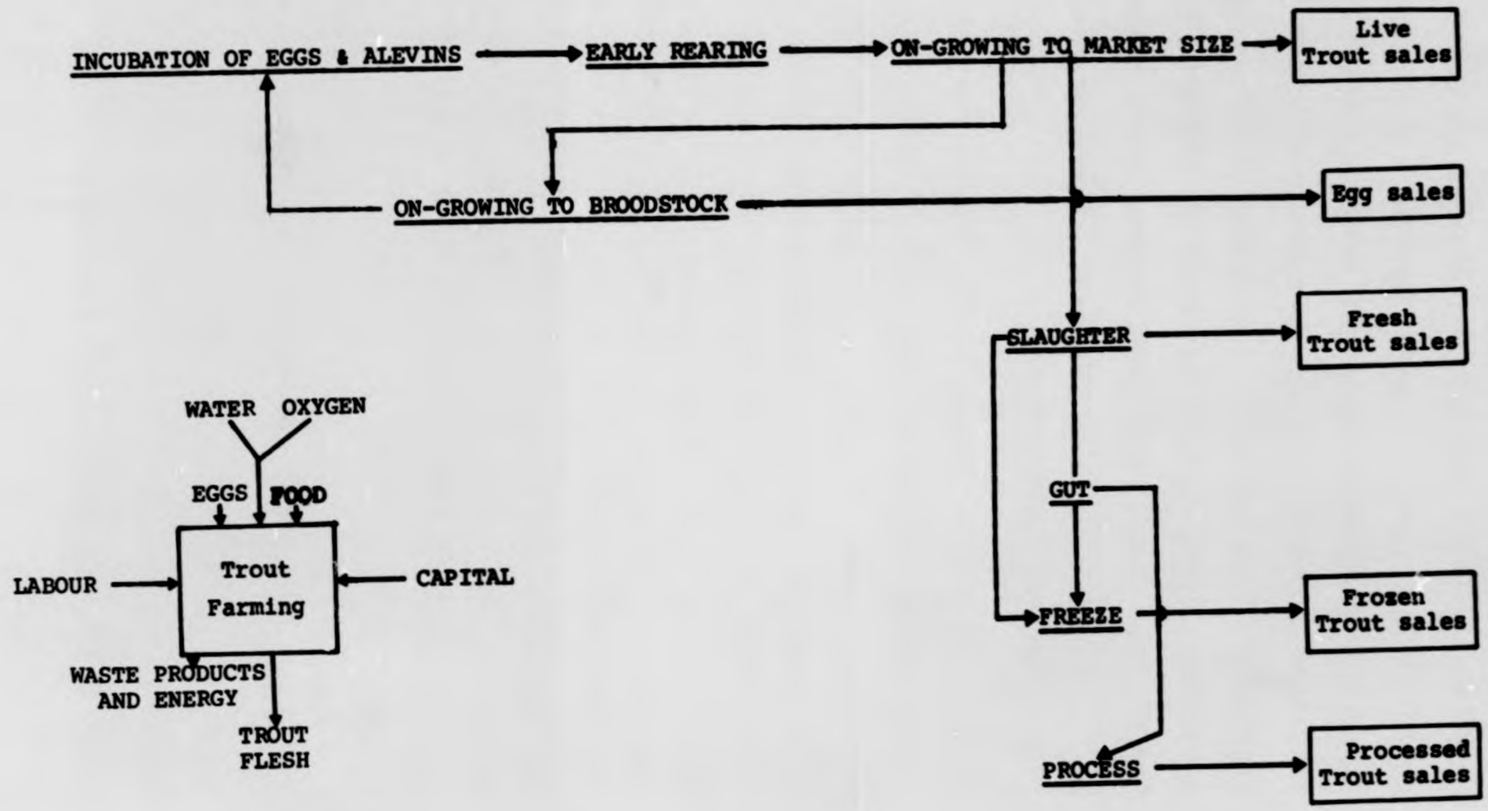
Hatcheries, as described here, may be defined as systems for accommodating trout eggs and newly-hatched yolk sac fry (alevins) from the start of egg incubation until the fry commence to feed. It is customary to provide a device, e.g. a perforated metal tray, on which the eggs are placed for incubation and which will permit the hatching fry to pass through leaving behind the egg shells. Traditionally the perforated hatching trays have been placed within wooden rectangular boxes in series (Fig. 12) and the whole fed by a flow of water and protected from direct sunlight inside a hatchery building. A common

FIGURE 11

Diagrams to indicate the functional components involved in trout farming.

a) Flow chart of the processes leading to five different trout products.

b) Diagram of the main inputs to, and outputs from, a trout farming operation.


INCUBATION OF EGGS & ALEVINS
EARLY REARING
ON-GROWING TO MARKET SIZE
Live Trout sales
ON-GROWING TO BROODSTOCK
Egg sales
SLAUGHTER
Fresh Trout sales
GUT
FREEZE
Frozen Trout sales
PROCESS
Processed Trout sales
WATER
OXYGEN
EGGS
FOOD
LABOUR
Trout Farming
CAPITAL
WASTE PRODUCTS AND ENERGY
TROUT FLESH

modification entails placing the trays in vertical stacks down which the water flows. This is more economical on hatchery area and is commercially available (Fig. 13) in moulded polypropylene. These systems do not require transfer of the eggs or fry before first feeding.

Buss (1959) described a method for incubating trout eggs in vertical glass jars. This is very economical on space relative to the above methods if the fry are hatched within the jars. Cappello (1967) described a vertical 'trout embryonator' for the incubation of 400,000 eggs (Fig.14) but recommended that the eggs be poured on to conventional hatchery trays before hatching. In these systems the direction of water flow is upwards and it is usually necessary to inject a fungicidal agent into the water regularly since dead eggs (which may act as a focus of fungal multiplication) cannot be physically removed. Such intensive egg incubation systems require a lack of suspended matter in the water, which is therefore frequently passed through a filter (e.g. gravel bed) before use.

5.3 Early-rearing systems

Formerly feeding fry were placed in various types of earth pond where they were reared until market weight, i.e. there was little or no distinction between systems for early-rearing and on-growing. However, disease considerations encouraged the use of fabricated (non earth pond) systems from first feeding until fish had achieved a unit length of *ca.* 6 cm (Bregnballe, 1963). Such systems are designated 'Early-rearing' systems and are now widely used and considered to have certain advantages other than disease prevention, e.g. control,

FIGURE 12

Interior of trout hatchery, showing tiered wooden incubation trays (N. Wales).

FIGURE 13

Vertically stacked incubation trays for salmon and trout eggs (Heath, U.S.A.).

FIGURE 14

Diagram of trout egg embryonator (modified after Cappello, 1967); interior diameter = 40 cm.; vertical height of egg stack = 70 cm.

B = Base; F = Funnel for fungistat; I = Inlet; O = Outlet; V = Valve for fungistat injection.

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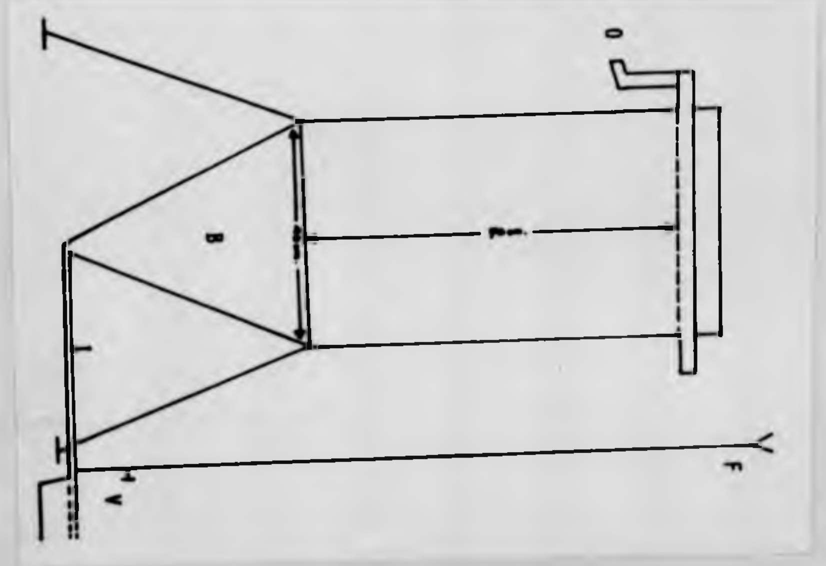

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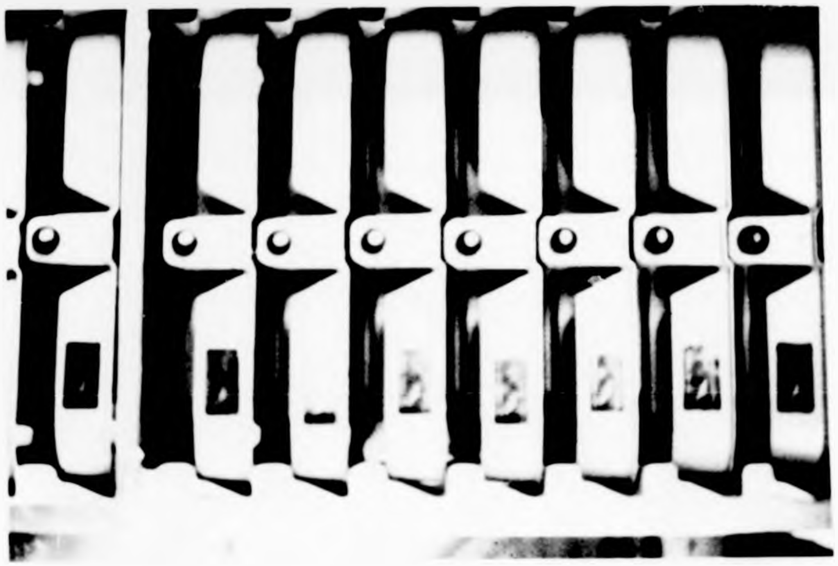

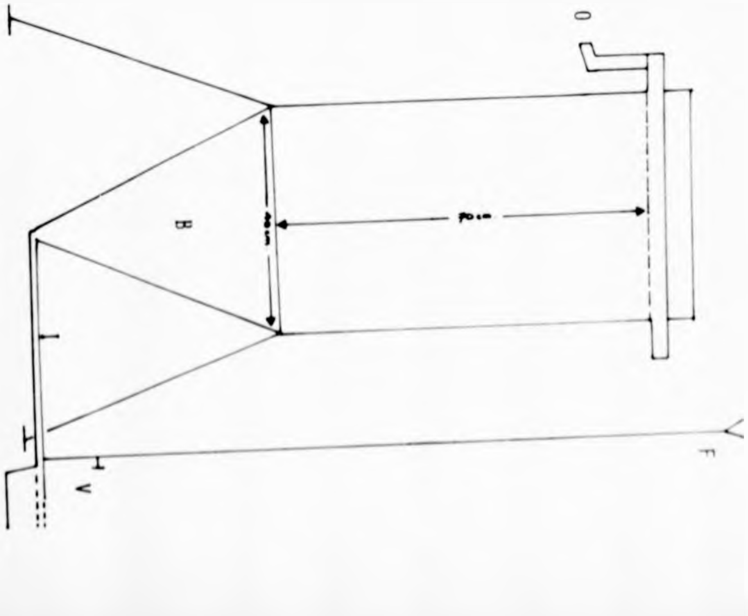

ease of feeding.

1. Earth pond systems

These may be identical with earth ponds for on-growing (see p. 77), or they may be of smaller volume, e.g. simple excavated earth ponds, 30' x 15' x 2.5' deep (Gaarsdal dambrug) or 20' x 2' x 1' deep (Hometoun), covered by netting etc. against predators.

2. Rectangular fry tanks

Fry tanks used in Denmark are commonly of dimensions ca. 20' x 2½' x 2½' deep. They are usually formed in concrete (occasionally fibreglass) and built in parallel so that adjacent tanks share a common wall. The water supply to each tank is regulated by a tap valve and the depth in the tank is controlled by dam boards over which the effluent water spills into a drainage channel. Fry tanks may be constructed outside or inside a hatchery building; the latter facilitates control and automatic feeding (Fig.15)

3. Fry Raceways

A raceway is a relatively long and narrow pond in which high water exchange rates are commonly used to permit reuse of the water through a series of ponds. Fry raceways are popular in Italy, usually formed in concrete and utilise a lower stocking density than fry tanks. Fig. 16 (Dingle Trout Farm) indicates a common design comprising a block of 10 ponds divided into two sets of 5 ponds in series, of which each pond is 10' x 45' x 1' deep.

4. Square and Circular Tanks

Square and circular tanks for early rearing are usually constructed in fibreglass or concrete with a perimeter inflow pipe and a central drain. The latter often incorporates

FIGURE 15

Concrete fry tanks in parallel, showing tap inlets and automatic feed hoppers with compressed air pipeline (Viborg, Denmark).

FIGURE 16

Concrete fry raceways in paired series of five units, showing screens and predator netting (Dingle, Ireland).

FIGURE 17

Excavated earth pond unit showing wooden inlet and outlet monks and feed hopper; dimensions: ca. 100' x 30' x 4' deep. (Vejle, Denmark).

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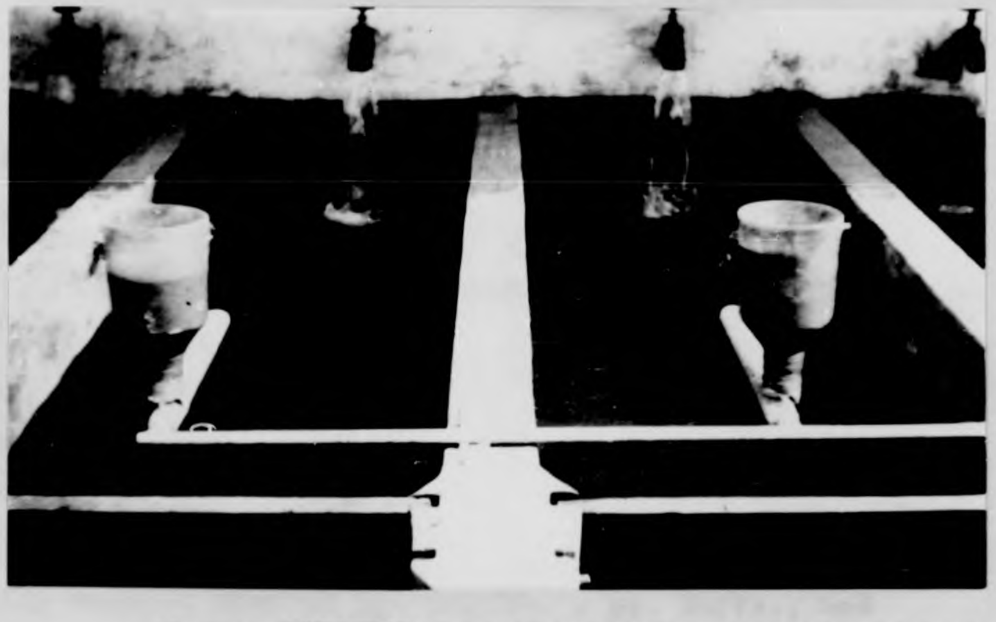

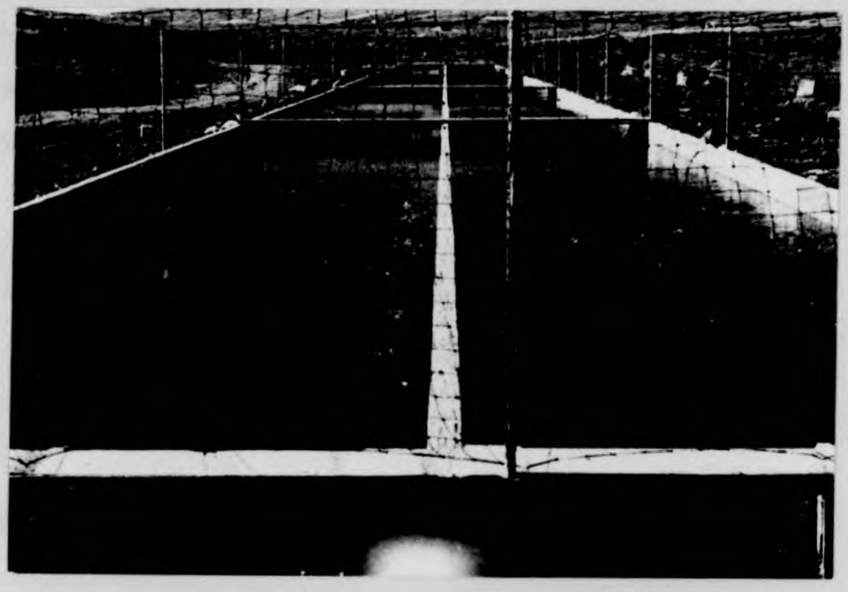

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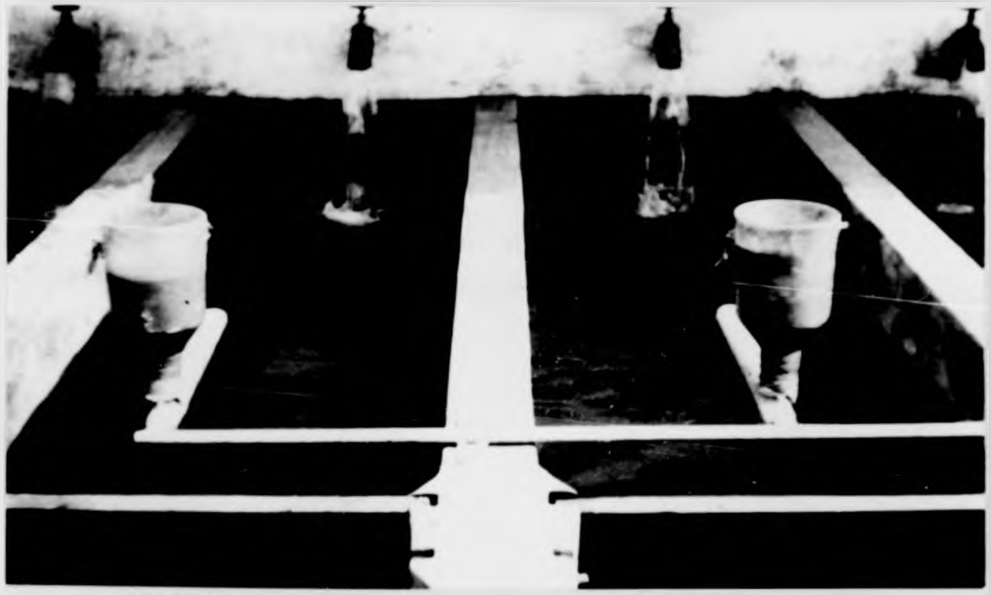

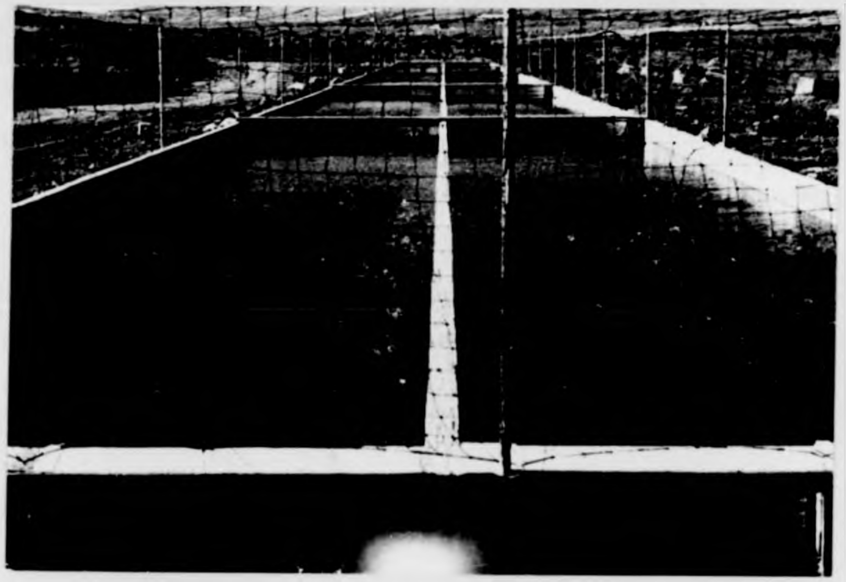

a stand pipe above a venturi in order to create a vortex flow and facilitate self cleaning. A fibreglass square tank, 6' x 6' x 1.5' deep, was designed to hold 200 lbs. of fry at a flow rate of 7 - 10 g.p.m. (Plade, 1972).

5.4 On-Growing Systems

On-growing is defined here as that part of the production cycle of a trout farm which follows early-rearing up till marketing of the final product. Facilities for on-growing thus usually receive fish at ca. 100/lb. - ca. 60/lb., and accommodate fish until they are ca. 2/lb. (or heavier occasionally, notably in marine farming). It is possible to classify the different systems for on-growing trout into various categories.

5.4.1 Earth ponds

(i) Unexcavated

A trout farm may be established under certain circumstances by erecting dams, weirs, etc. along a watercourse so that a series of ponds are thereby formed. The natural topography of the site will determine the shape (and suitability) of the ponds.

(ii) Excavated

Excavated earth ponds are used for on-growing trout on all Danish trout farms. In this case, each pond is usually ca. 100' x 30' x 4' deep and is excavated in terrain with poor permeability and maintained unlined (Fig. 17). If the site permits it, such ponds are usually placed in parallel and the effluent water passes, via wooden monks into an outlet channel which is also stocked with fish (Fig. 18). Flow rates into each pond (Summer) may be 150-200 g.p.m., with an overall water exchange rate of ca. 0.27 changes/hour (at which the stocking densities for fish at 2/lb. are commonly 0.1-0.2 lbs/ft.^{3}).

5.4.1 Raceways

Raceways are designed in order to attain a homogeneous environment and utilise larger flow rates than earth ponds. Buss and Miller (1971) claim that linear raceways 'having the advantage of approximating identical water conditions from side to side, ... have the disadvantage of deteriorating water quality as the flow progresses through the unit' represent, under most conditions, the most efficient rearing areas for trout. Raceways are either excavated in earth or fabricated.

(i) Earth Raceways

Raceways excavated in earth are usually ca. 100' x 8' x 1.5' deep with a fall of 8" or less and are often constructed in series. The inlets and outlets of each pond are often reinforced with concrete blocks, logs, etc. and commonly there is a drop of 1' with a splashdown from one pond to another in order to improve aeration (Fig. 19). Erosion problems are a feature of many earth raceways. In the Ringkøbing fjord in Denmark, brackish water raceways have been constructed, 300' x 30' x 3', and adequate water circulation is maintained by means of water impellers at the end of the raceway.

(ii) Fabricated Raceways

These are commonly the same dimensions as earth raceways and constructed in concrete, brick or fibreglass cement. They are commonly constructed as 3 ponds in series (total length 300') with a flow rate of 200-400 g.p.m. and a water exchange rate of three changes/hour (at which the stocking

FIGURE 18

Aerial view of Danish trout farm, showing plan of earth ponds in parallel draining into central outlet channel (46 production ponds and 30 small experimental ponds at Brøns, Denmark).

FIGURE 19

Excavated earth raceway series of 3 units, showing outlet screens (Croy, Scotland).

FIGURE 20

Concrete raceways in parallel units down a gradient, showing pumphouse for seawater line (Loch Fyne, Scotland).

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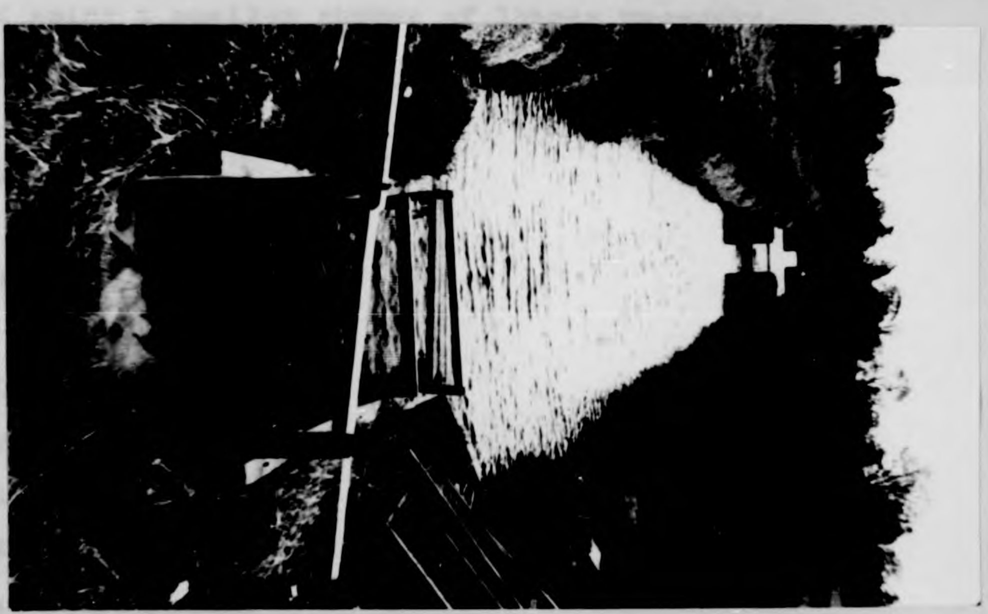

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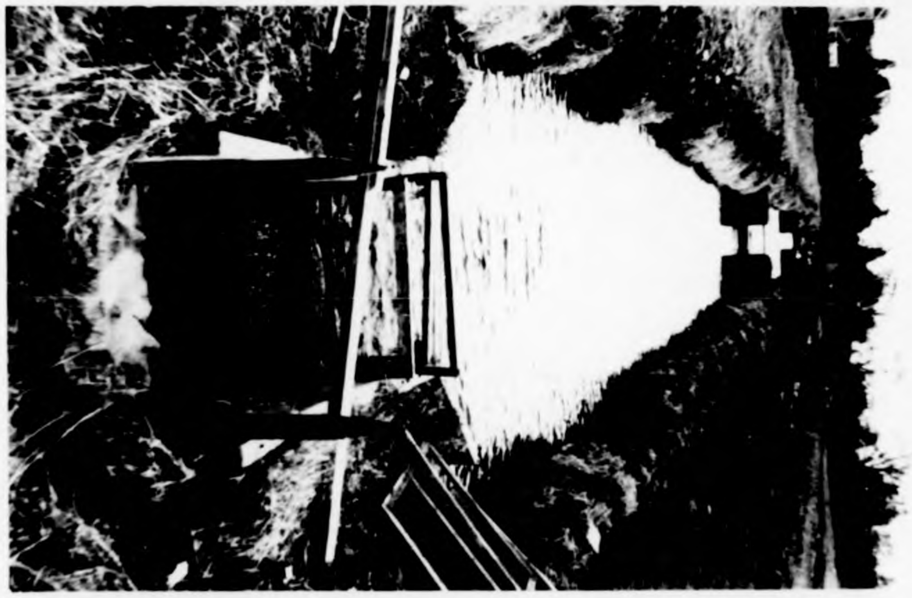

densities in the first raceway for fish at 2/lb. are commonly ca. 2 lbs./ft.^{3}). Buss and Miller(loc.cit)referred to certain features of raceway design:

(a) the necessity for quick drainage of each unit in a series

(b) the value of designs allowing vehicular access at all points in all sections of a series

(c) effecting a suitable compromise between splitting the water into many series of raceways to give a compact block design, and using a smaller number of longer raceways.

Although originally designed to utilise the large flow rates from springs in U.S.A., such systems are now also used to rear trout in pumped sea water (Fig. 20) and fresh water (Fig. 21). The nature of the terrain is not as critical as in the case of earth ponds (U.S. Fish and Wildlife Service, 1964).

5.4.3 Circular Tanks

As described under 'Early rearing', circular tanks with a central drain may be constructed to achieve a self-cleaning action. They are currently constructed in fibreglass, concrete and expanded polystyrene.

(i) Fibreglass circular tanks

Moulded tanks of glass fibre reinforced polyester are available in various sizes and have the advantage of being portable. One design (Fig. 22) had dimensions of 15' diameter x 4' depth and for a flow rate of 200 g.p.m., was claimed to have a capacity for fish at 2/lb. of 1 ton (Plade, loc.cit.).

(ii) Concrete circular tanks

Robinson and Vernesoni (1969) described a pond whose construction obviated the high cost of forms by utilising

FIGURE 21

Trout farm comprising a system of brick raceways using pumped freshwater (pumphouse in left foreground at Loch Awe, Scotland).

FIGURE 22

Moulded fibreglass circular tank, showing peripheral inlet, central outlet and feed hopper (Bannockburn, Scotland).

FIGURE 23

Sectional polystyrene circular tank, showing peripheral inlet and central outlet (Meriden, England).

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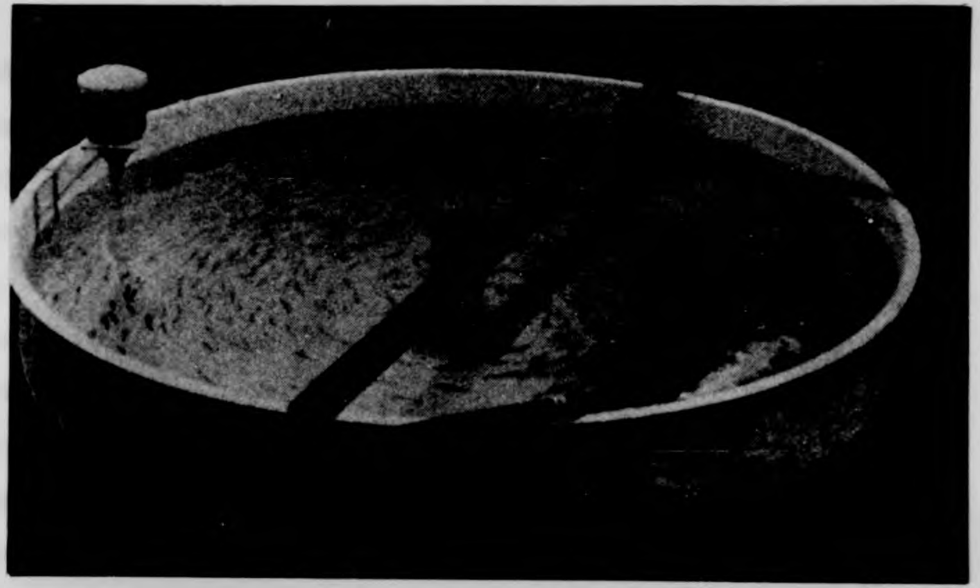

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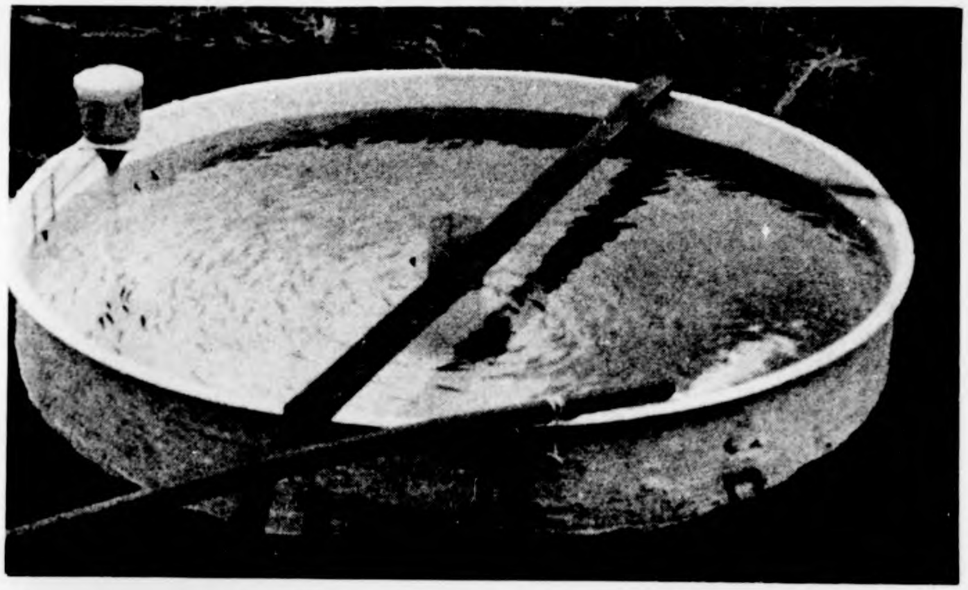

preformed concrete silo staves. These are locked in position with galvanized silo bands and the joints sealed with mortar before a concrete floor is poured into the circle of staves. One Scottish trout farm has recently installed two such tanks, 30' diameter x 5' depth, in each of which up to 4 tons of trout have been held at 2/lb. (Wallace, personal communication); these are available in 3' increments of diameter from 30' in the U.K. (Howard Harvestore, personal communication).

(iii) Expanded Polystyrene tanks

25.5' diameter sectional tanks in expanded polystyrene are available in the U.K. from Vortex Ltd. (Fig. 23). The thermal properties of polystyrene would increase the attractiveness of using heated water and the manufacturers market a filtration unit for the centre of each tank. Such tanks are portable and a carrying capacity of 1 ton at 2/lb. is claimed for a flow rate of 100-133 g.p.m. (Chattaway, personal communication).

5.4.4 Extensive and Semi-extensive Systems; Enclosures

The systems described hitherto represent intensive stocking relative to natural populations. However, since addition of mineral fertilizers to oligotrophic lakes is known to improve growth rates of Brown trout (Munro, 1961), one may consider culture of trout at stocking rates approximating to the natural state, i.e. extensive culture. In practice, the lack of control discourages such systems except as an adjunct to the leasing of lakes for recreational purposes. Recent Japanese work (Gordon, personal communication) has indicated that trout may be conditioned to assemble at a feeding point by means of an acoustic signal, and limited trials have suggested some possibilities for an extensive system at a gravel pit in Hanover (Muller, personal communication). Under certain circumstances there might be a trade-off between the high risks involved in such uncontrolled systems and the high growth rates possible due to natural and artificial feeds and lack of crowding stress. Various attempts have been made to achieve a compromise by semi-extensive systems.

In Norway, coves, sounds and embayments have been fenced off, dammed, netted, etc. in order to provide semi-extensive marine or brackish water systems for trout culture (Jensen, 1966). Ponds thus created have varied in area up to 430,000 ft.^{2} and have relied for aeration upon either the tidal circulation or submerged pumps. Problems include (i) dangers of the enclosure breaking, e.g. in storms, (ii) difficulties of surveillance, control, feeding, harvesting (iii) formation of areas with low oxygenation, e.g. due to poor circulation and accumulation of waste products, but this may be compensated by unusually rapid growth (Berge, loc. cit.). One such system exists in Scotland at Ardtoe, Argyll where a 2 hectare enclosure has been constructed for white fish culture; the enclosure was formed using two concrete sea walls on rock foundations, either side of a central island and was in the intertidal zone, i.e. the area on the foreshore lying between low water spring tides and high water spring tides (Milne, 1972) (Fig. 24).

A sublittoral enclosure system was constructed at Loch Strom, Shetland for intensive trout culture (Fig. 25). This comprised a rigid framework of galvanised steel from which was suspended fourteen bag nets, each 30' x 44' x 10' and constructed in 0.4" Courlene mesh (Milne, 1970a). The water

FIGURE 24

Diagram of 5 marine fish culture systems (after Milne, 1972).

A = Anchor

B = Buoy

P = Pumped sealine

HSTL = High water spring tide level

S = Sea level

SB = Sea bed

LSTL = Low water spring tide level

Systems:

1. Shore based facility using pumped water
2. Fixed sublittoral sea enclosure
3. Midwater facility
4. Floating system
5. Sea bed cage

N.B. The area of shore lying between levels HSTL and LSTL may be utilised for intertidal systems.

FIGURE 25

Sublittoral enclosure using bag nets, showing access catwalk (photograph by P.H. Milne of Loch Strom, Scotland).

FIGURE 26

Floating marine system using 2 bag nets, showing wooden flotation collar (Rylandsvag, Norway).

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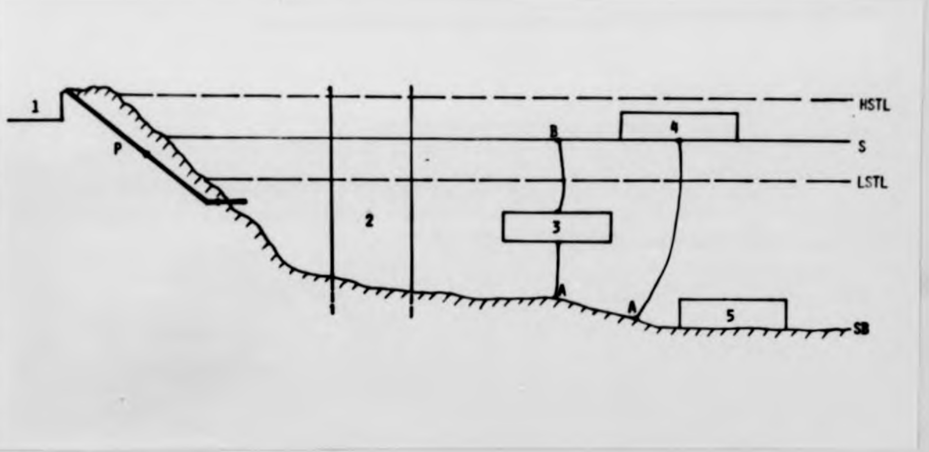

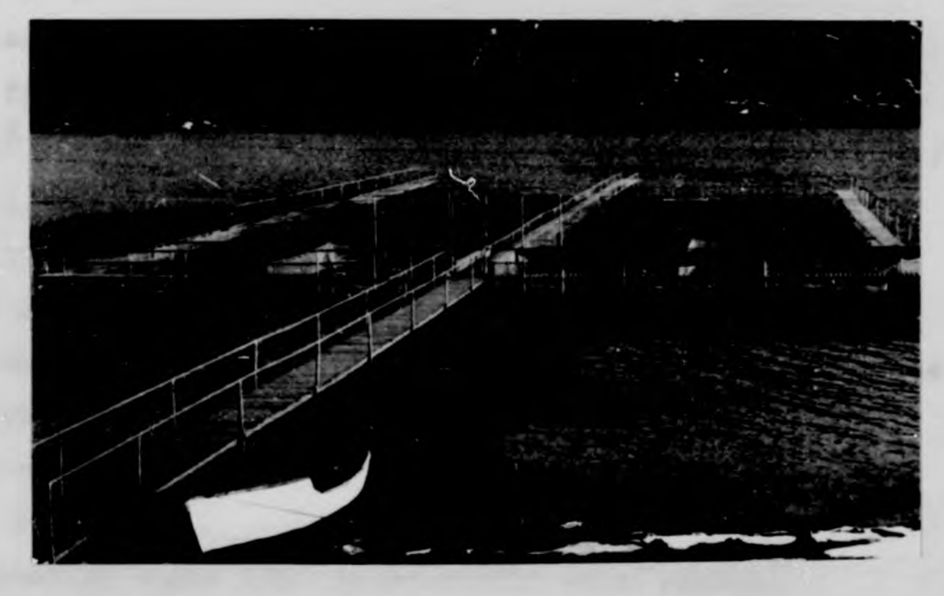

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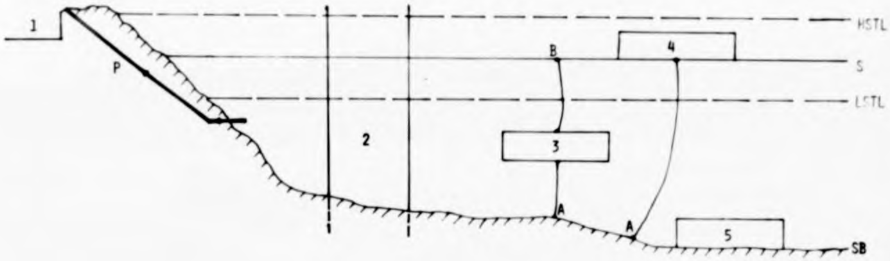

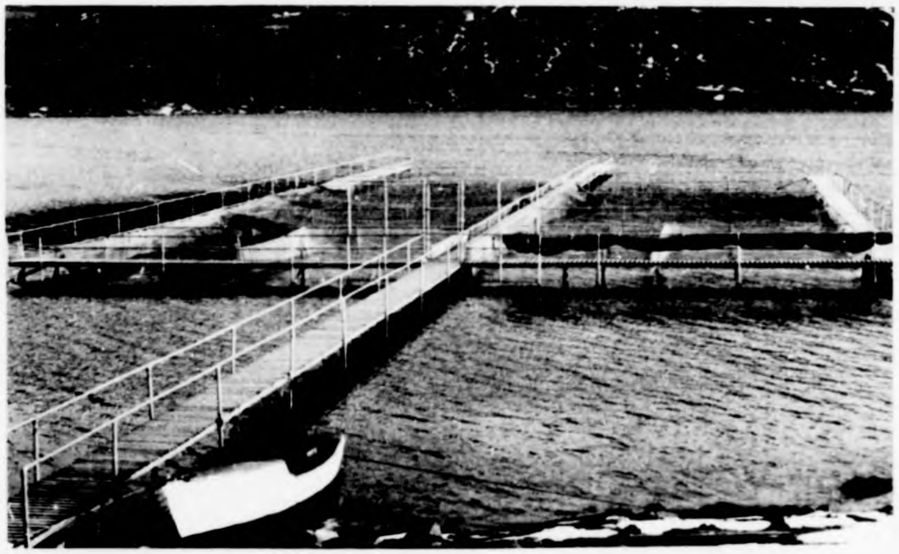

depth varied from 10' to 16' and a catwalk was provided thus enabling direct access to the structure and permitting better control than with extensive systems. *Ca.* 1.1 tons of trout were produced in 1970 but poor circulation has halted production. Such systems have been used in Japan (Allen and Shelbourne, 1966) and one form on the Baltic sea involved suspending bag nets from the supports underneath the harbour pier.

5.4.5. Floating Systems

Floating systems are commonly used in Norway for trout culture in fjords and the popular range of rearing volume is 700-2700 ft^3 (Fig. 26) with a stocking density of *ca.* 1.8 lbs./ft^3 (Jensen, *loc.cit.*). A few larger floating ponds are used (e.g. 130' x 130' x 13' with 3' high perimeter fence and 1" square mesh nylon net with anti-fouling copper impregnation) and flotation is provided by timber frames, expanded polystyrene collars, empty oil drums, etc. Marine Harvest Ltd. experimented with octagonal cages for trout and salmon culture at Lochailort, Inverness-shire, but have abandoned them in favour of square floating cages (24' x 24' x 12') with stocking densities of up to 2.5 lb./ft^3 (Bradley, personal communication).

Trout appears to adapt well to fresh water floating cage culture. Collins (1972) attained stocking densities in U.S.A. of 3.4 lbs./ft^3 in cages 3' x 4.5' x 4', although the galvanised welded wire material caused sores on the fish. Floating nets with catwalk access (e.g. Fig. 25) are used successfully at a German gravel pit (Muller, personal communication) and experiments are currently being undertaken to determine the usefulness of floating nets for trout culture at two fresh water locations in Scotland.

5.4.6 Miscellaneous Systems

(i) Rectangular Circulating Raceways

Rectangular circulating raceways (Fig. 27) have been chosen by Burrows and Chenoweth as being the most efficient systems for certain operating criteria (loc. cit.). However, these workers wished to produce trout with a good stamina for restocking irrespective of cost considerations and it is unlikely that table trout producers would invest in such systems.

(ii) Silos

Buss *et al.* (1970) developed and tested a vertical storage silo (7.5' inside diameter x 16.5' high) for trout culture. The inlet was just above the centre of the silo base and the water passed vertically up the silo. Stocking densities were very high (8.53 lbs./ft^3) but yield in terms of flow rate (13.8 lbs./g.p.m.) was low. The authors claimed that recirculation of the water would, if feasible, make such silos attractive commercially because of their economy in land use and portable nature.

5.5 Operating systems

5.5.1 Water

Water may be pumped if otherwise inaccessible or inadequate, e.g. due to lack of running water, unsatisfactory falls, etc. It may then be filtered in order to remove large objects which would cause blockages and this process may be automated with large flow rates. Lime is also added as required.

5.5.2 Feeding

The choice of feeding method depends on several factors, including the nature of the diet (see Chapter 7). Automatic feeders are usually used only for dry pelleted diets (Fig. 28) and are often activated by time switchgear which triggers e.g. compressed air via a pipeline. Dry pellets may also be dispensed by hand or by the fish themselves using a self-feeder ('Demand' or 'Pendulum' feeder). Automatic feeding of moist diets is rarely practised and is technically difficult.

5.5.3 Grading

The methods used for grading fish into different weight classes is influenced by several factors, e.g. fish size, nature of holding facility and is capable of automation under certain circumstances (Fig.29).

FIGURE 27

Diagram of rectangular circulating raceway unit, showing direction of water movements (arrowed).

CI = Central island

I = Inlet pipe

O = Outlets

FIGURE 28

Self feeder ('demand' feeder) with catwalk access, showing pendulum inserted into floating pond (Hannover, West Germany).

FIGURE 29

Grading device floating in outlet channel of earth pond trout farm, showing one grading riddle (New Galloway, Scotland).

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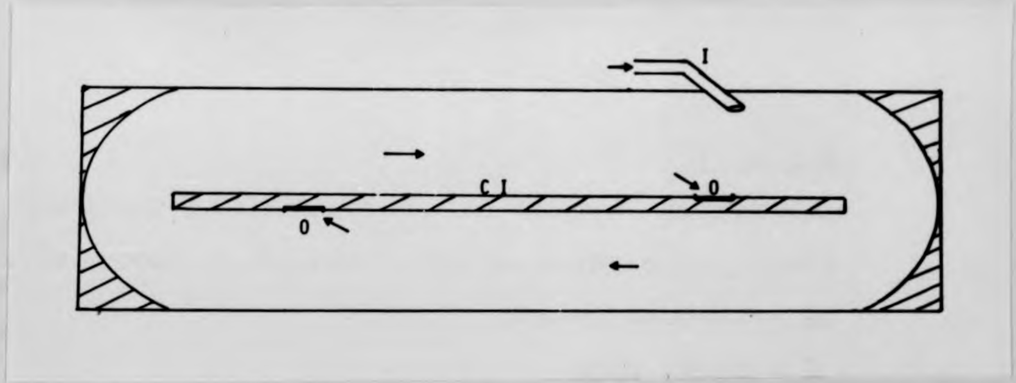

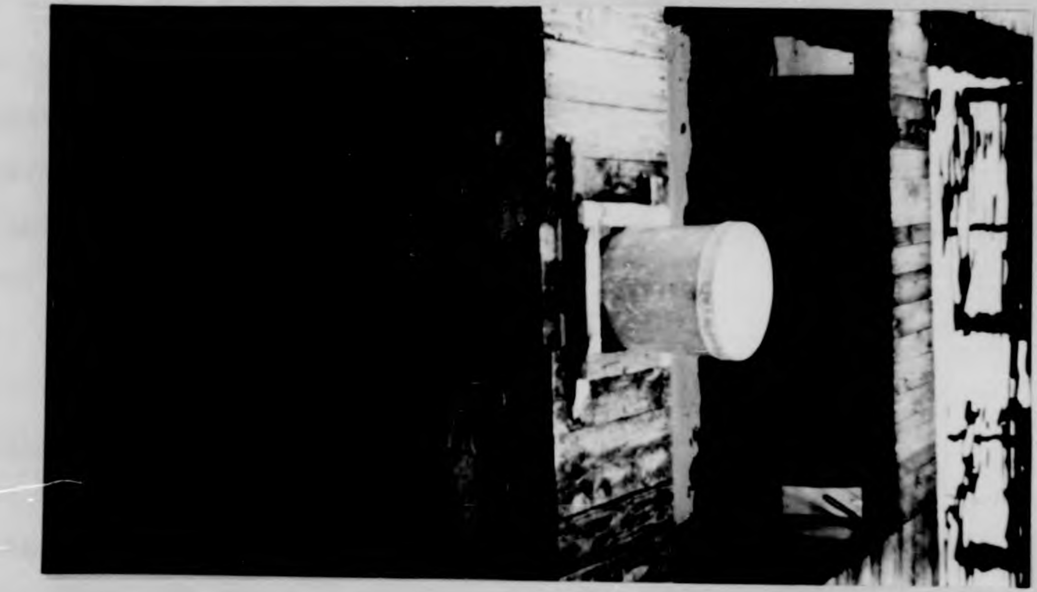

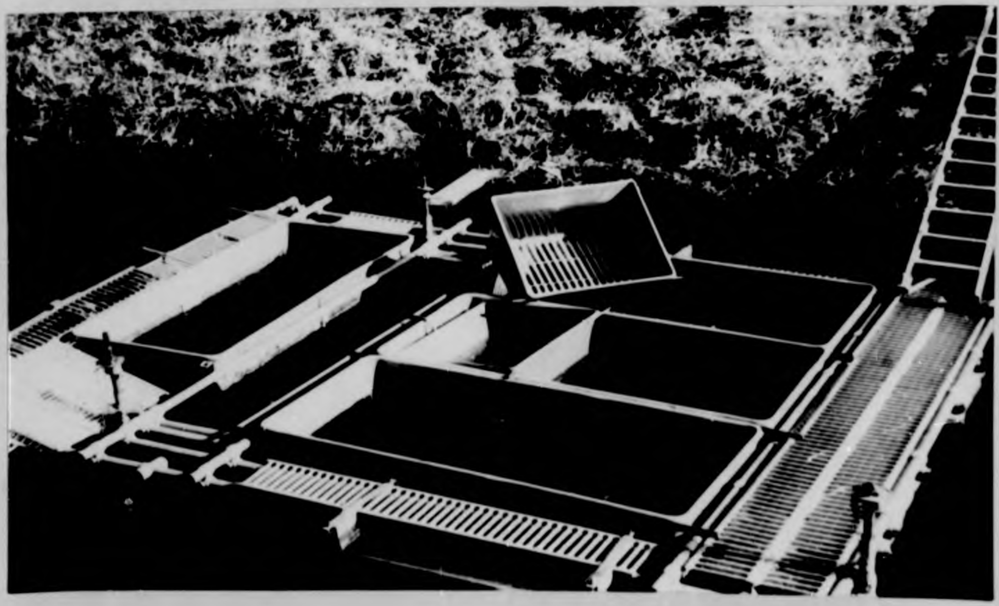

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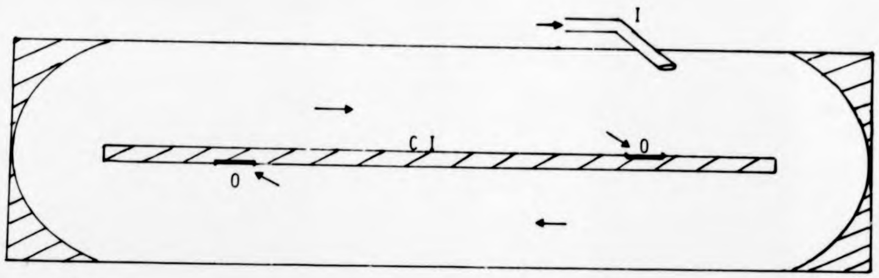

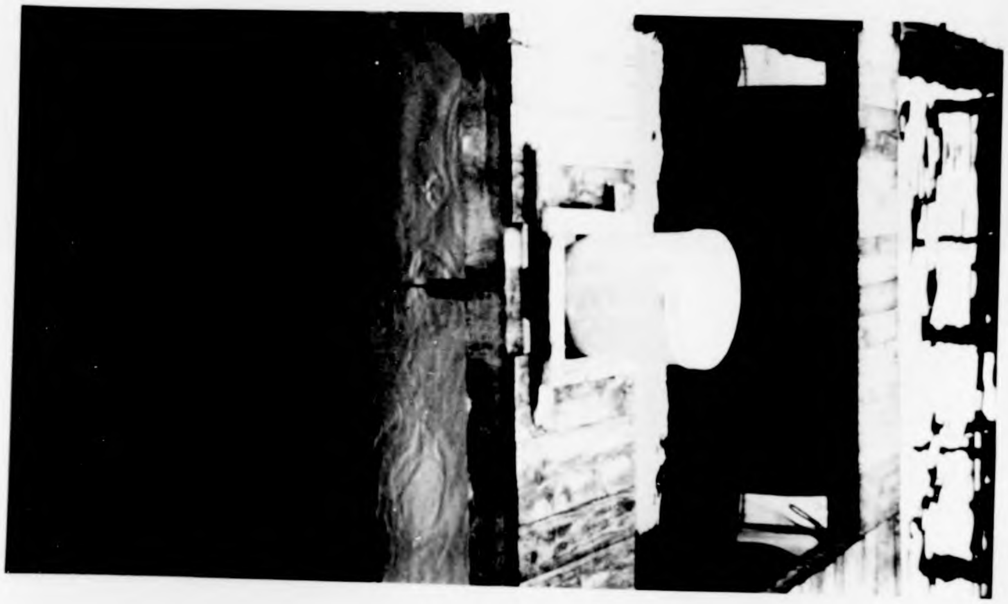

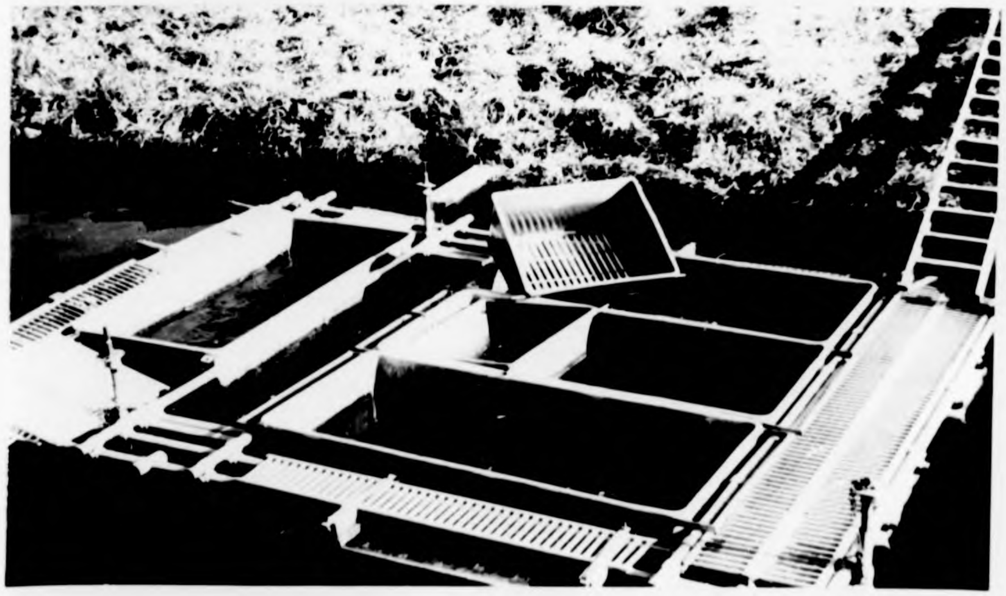

CHAPTER 6

EVALUATION OF SITE POTENTIAL FOR TROUT CULTURE

6.1 Introduction

From the foregoing, it would appear that any evaluation of a site in terms of its potential for trout culture would need to take account of the characteristics of water and land at the site and the alternative technological systems available for their exploitation. Thus factors of water quality will determine whether the site might permit survival and/or encourage growth of trout. However, it is necessary to obtain quantitative information on water flow rates, temperatures, etc. in order to make a meaningful assessment of potential production levels, on which a consideration of economic factors may then be based.

6.2 Water requirements

It has already been demonstrated that trout require particular ranges of different characteristics of water in order to live and grow, particularly under intensive conditions. Since it is the water inflow which provides the medium for oxygen and other factors, a consideration of the Oxygen and water requirements of Salmonids, under conditions of intensive culture is relevant.

Elliot (1969) suggested that the Oxygen requirements for Chinook Salmon could be calculated by use of the following formula:

$$Y = a.T - b$$

where Y = Oxygen requirements of the specific weight of fish in p.p.m. Oxygen per lb. of fish per gallon per minute (g p.m.) of inflow.

T = temperature of water (^{o}F)

a and b are constants.

As has been pointed out by Liao (1971), Elliot does not specify the loading density of the tanks which he used (in terms of the weight of fish per unit volume of water) which affects activity levels, nor does he indicate whether this equation is applicable to Oxygen consumption determinations outside the range examined (1.85 to 17.5 gm. per fish).

Haskell (1955) described a method of calculating maximum loading levels based on two major premises.

(i) carrying capacity is limited by (a) Oxygen consumption

(b) accumulation of metabolic products.

(ii) amount of Oxygen consumed and the quantity of metabolic products are proportional to the amount of food fed.

Using these principles, Willoughby (1968) attempted to predict the capacity of a hatchery on the basis of volume and Oxygen content of the water supply. Using 15 years of data from U. S. State hatcheries, he suggested the following (it may be noted that there are 5.45 m.tons of water in 1 g.p.m. over a period of 24 hours):

$(Oa - Ob) \times 0.0545 \times g.p.m. = \text{lbs. of food per day}$

where Oa = Oxygen content of influent water (mg./l.)

Ob = Oxygen content of effluent water (mg./l.)

g.p.m. = flow rate of influent (g.p.m.)

Once again, the loading density is not specified; also there are considerable differences in composition of one food type to another and, whereas this relation might work well for some brands of commercial dry pellets, it would probably be less satisfactory when wet feeding with trash fish is practised.

Despite these theoretical limitations, this method has certain advantages under particular circumstances, and is discussed later.

In an attempt to establish a carrying capacity formula for trout hatcheries, Piper (1970) proposed the use of a 'loading factor', also based on Haskell's assumptions. In his formula, Piper substituted fish size (in inches) for weight of food fed daily, since on many trout farms there is often a linear relationship between these two factors:

$$F = W/L \times I$$

where F = Loading factor
W = known permissible weight of fish (lbs.)
L = length of fish (inches)
I = rate of water inflow (g.p.m.)

Such a method suffers from the drawbacks of Willoughby's equation and has only been used for fish up to 11 inches in length. Furthermore, it assumes constant conditions in the inflow water, and (even less likely) constant conditions throughout the system. Nevertheless, compilation of such data obtained under different temperatures may provide useful if unsophisticated guides to the estimation of feasible weights of fish in relation to unit inflow rate (as in the table of data provided by Cannady and cited by Piper).

Burrows and Combs (1968) postulated that, for Chinook Salmon, the carrying capacity (lbs. of fish/g.p.m. water) was inversely proportional to water temperature and proportional to fish size. They used the criteria of (a) density (lbs./cubic foot) and (b) capacity (lbs./g.p.m.) but Westers (1970) pointed out the dangers of using these criteria without information about the rate of exchange being given. To illustrate this, he cites the following example:

(a) Pond A can carry 4" Rainbow trout at a carrying capacity of 50 lbs./g.p.m. inflow.

(b) Pond B can carry 4" Rainbow trout at a carrying capacity of 10 lbs./g.p.m. inflow.

Thus Pond A appears to be more efficient. However, the preference may be reversed when more information is given:

(a) Pond A is a dirt pond with a volume of 32,500 ft^3 (0.5 acres with an average depth of 18"); the inflow is 100 g.p.m., and the capacity is 5,000 lbs. of 4" Rainbow trout at a density of 0.15 lbs./cu. ft. of water.

(b) Pond B is a raceway unit with a volume of 2,400 ft^3 (100' x 12' x 2' deep). The inflow is 5,000 g.p.m. The capacity is 5,000 lbs. of 4" Rainbow trout at a density of 2.08 lbs./ft^3 of water.

It is the rate of exchange (R) which makes the difference in this comparison and which is therefore incorporated in Westers' equation:

$$\text{lb./g.p.m.} = \frac{(\text{lb./ft}^3 \times 8)}{R}$$

where R = rate of exchange (changes/hour)

8 represents a conversion factor equating g.p.m. to ft^3/hour. Note that Westers presupposes an adequate initial content of dissolved Oxygen. If this is not a limiting factor, his paper is of considerable practical value in providing graphical relationships between stocking density (within the range from 1 to 9 lbs./ft^3) and water exchange rate (within the range from 1 to 6 changes of water/hour) for six different weight/length classes (1 gm : 1.7"; 3.5 gm : 2.5"; 8 gm : 3.5"; 16 gm : 4.5"; 27 gm : 5.5"; 43 gm : 6.5") at five different temperature ranges (40° - 44°F., 45° - 49°F.; 50° - 54° F.;

55^{o}- 59^{o}F.; 60^{o} - 64^{o}F.). This information appears to result more from empirical observation than from critical scientific method but is nonetheless of considerable value to the fish culturist. Thus, for design purposes, such data is readily amenable to being incorporated into the formulae for raceway design proposed by Buss and Miller (1971). The latter authors advanced three formulae:

(a) To determine water flow: $Q = W.D.L.C_1$ (0.1247)

(b) To determine total poundage of fish produced: $P = Q.C_2$

(c) To determine total length of raceway unit: $V = P/C_3 = W.D.L_t$; Hence $Lt = P/W.D.C_3$ when the parameters used are defined as follows:

Lt = total length of propagation unit (ft.)

Q = water flow (g.p.m.)

W = raceway width (ft.)

D = depth of water (ft.)

L = length of raceway unit (ft.)

V = total volume of water in propagation unit (cu.ft.)

P = fish production (lbs.)

C_1= water exchange rate (changes/hour)

C_2= expected fish production (lb./g.p.m.)

C_3= carrying capacity of water volume (lb./ft^3).

These formulae do not in themselves provide any information as to what values of C_1, C_2 and C_3 are likely to provide feasible conditions for fish culture. It is suggested that a "desirable" range of water exchange rate would be two to three changes/hour. Under conditions of high temperature, slow exchange or low Oxygen levels, one might expect to produce only 30 lbs. of fish/g.p.m. inflow; under more favourable conditions this might, however, be increased to 80 lbs.

Similarly, a high pH and temperature will prevent the loading densities capable of being achieved under alternative circumstances.

In an attempt to overcome these difficulties, Buss and Miller refer to the aforementioned work of Willoughby whose formula linked food requirements of trout to Oxygen consumption and flow rates. The former authors paraphrased Willoughby's formula and data and proposed that:

$$F = \frac{(X - C_4)\ C_5\ .\ Q}{C_6}$$

where F = fish feed (lb./day)

P = fish production (lb.)

X = Oxygen content of water supply (p.p.m.)

Q = volume of water supply (g.p.m.)

C_4 = threshold Oxygen tolerance (p.p.m.)

C_5 = conversion factor (5.45×10^6 cc./g.p.m. for 1 day)

C_6 = Oxygen required to metabolize 1 lb. of trout pellets (cc./lb.)

C_7 = rate at which Oxygen is consumed by trout (% body weight/day)

L_t = maximum length of raceway before aeration is required (ft.)

They further propose that C_4 is normally 5 p.p.m. for Rainbow trout and C_6 is normally 100 cc./lb.

Thus $F = \frac{(X - 5)\ 5.45\ .\ Q}{100} = (X - 5)\ (0.0545\ .\ Q)$

Further assuming that 9" trout consume Oxygen at the rate of 1% of bodyweight daily, it is possible to determine the poundage of trout consuming (X - 5) parts of Oxygen in a given flow, as follows:

$F = C_7 \times P = 1\% \times P = 0.01\ P$, or $P = 100\ F$.

Referring back to their computation for length determination in the raceway design formula, Buss and Miller attempt to identify points in the system where aeration is required. Thus,

$$Lt = 0.667\ P/W.D.$$

$$Lt = \frac{0.667\ (100\ F)}{W.D.} = 66.7\ F/W.D$$

They also cite Kingsbury's measure of efficiency for trout hatcheries, namely that productivity can best be measured by the pounds produced per cubic foot of rearing space and by the pounds produced per gallon of flow per minute (Kingsbury, 1950).

If recirculation, pumping or aeration of water is not undertaken, then the capacity of a particular site for fish culture will be related to water flow. However, it does not necessarily follow that in order to achieve the optimal use of that water in the commercial sense, it is necessary to achieve maximum productivity at the site. In the short term, this may be the case, but it is possible that the long term consequences of this strategy will serve to increase the risk of various problems arising which will in their turn reduce overall productivity. Therefore, in order to maximize profits, it would seem rational for a fish farmer, all other things being equal, to have as his objective: the maximization of productivity insofar as this maintains an acceptable risk factor. Whereas this objective is likely to lie at the heart of many table trout production enterprises, it is less likely to be so formulated where live fish are being produced as the end-product.

Of the models for salmonid water requirements and hatchery carrying capacity considered hitherto, that of Westers (loc.cit.) is the most comprehensive. However, it refers specifically to Coho Salmon whose oxygen requirements are slightly greater than Rainbow trout. Moreover, neither the hydraulic patterns nor the altitude are considered; the former may be significant where fast flow rates (as in certain raceway farms) force upon the fish a higher activity level, and an increase in the latter reduces the saturation value of water for oxygen at a given temperature. Perhaps the most important omission is reference to the initial oxygen content of the influent water. These factors have, however, been incorporated into the recent study by Liao (1971) who has investigated the dissolved oxygen uptake rates of different sizes and species of salmonids under various operating conditions. These rates were plotted at different water temperatures against different fish sizes for Salmon and Trout in Fig. 30, from which he derived the formula: $O_2 = K \cdot T^n \cdot W^m$

where O_2 = Oxygen uptake rate in lbs. O_2/100 lbs. fish/day
K = rate constant
T = water temperature (°F)
W = fish weight in lbs./fish
m, n = slopes

This equation assumes an acceptable water quality and a loading density not exceeding 2 lbs./ft^3, and the values of K, m, and n used were tabulated, after tests on Coho and Chinook Salmon and Rainbow, Lake, Kamloop, Splake, Cutthroat and Steelhead Trout. Liao presented another equation relating dissolved Oxygen concentration to water temperature and elevation as follows:-

FIGURE 30

Diagram to indicate the relationship between oxygen consumption and water temperature for trout of varying unit weights. Data derived and modified after Mayo (1971).

Y = Rate of oxygen consumption (lbs./100 lbs. fish/day)
Y^1 = Water temperature (°C)
X = Weight per fish (lbs.)

Due to the log-log nature of the diagram and the consequent closeness of adjacent values, the following figures were omitted from the Y axis:
0.40, 0.60, 0.80 and 0.90.

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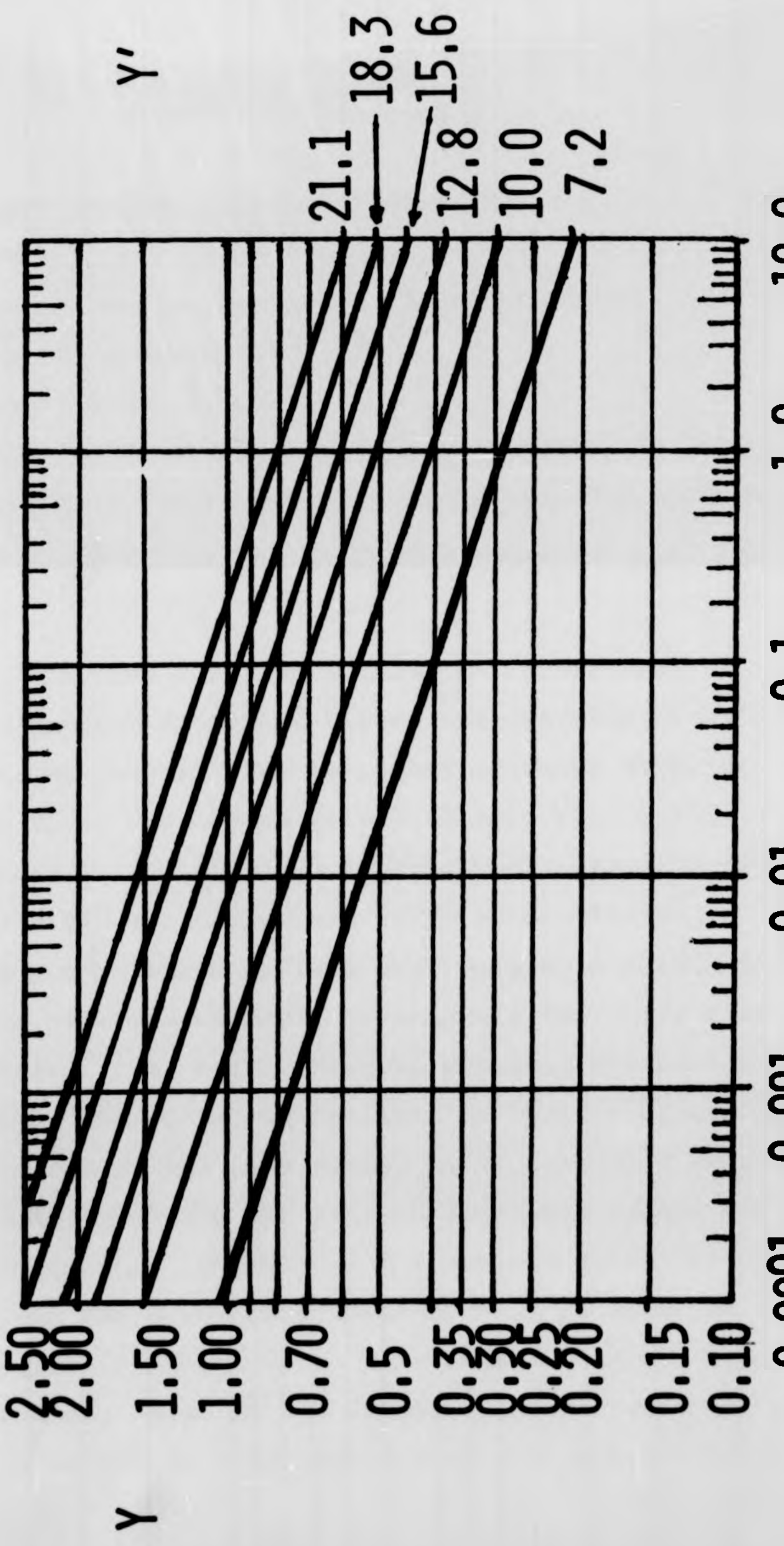

$$Ce = \frac{S \times 132}{T^{0.625}} \times \frac{760}{760 + \frac{E}{32.8}}$$

where Ce = dissolved Oxygen concentration (mg./l.) at water temperature, T, and altitude, E.

S = saturation factor of dissolved Oxygen

T = water temperature (^{o}F)

E = altitude (ft.)

Using these two formulae, he could then postulate the water flow required per unit weight of fish, i.e. the carrying capacity, as follows:

$$Q = \frac{1.2\ (Ce - C)}{O_2}$$

where Q = carrying capacity in lbs. of fish/g.p.m.

C = minimum dissolved Oxygen concentration (mg./l.)

For Trout, at temperatures less than or equal to 50^{o}F., the values of K, m, and n used were 1.90×10^{-6}, - 0.138, and 3.130 respectively, while at temperatures exceeding 50^{o}F., they were 3.05×10^{-4}, - 0.138, and 1.855 respectively.

This contribution by Liao must rank as a substantial advance on previous attempts to quantify the water requirements of salmonids. The model which he presents provides a means of computing the water requirements of Pacific Salmon or Trout, of a given weight and size class, at a particular temperature and altitude, provided the initial dissolved Oxygen concentration is known. In view of the minimum dissolved Oxygen requirements for Trout (see Chapter 4), it would be inadvisable to incorporate a value (C) of less than 5.0 mg./l. into Liao's third equation; also in the United Kingdom, it would be convenient to divide this equation by 1.2 in order to convert from U.S. to Imperial gallons, and this modification is made hereafter. One feature of his method, namely the maximal loading constraint of 2 lbs./ft^3, could be disadvantageous in the context of the Scottish environment. One of the raceway farms, whose capitalization is such as to ensure that maximal loading is particularly significant, has attempted to operate at loading densities of up to 6 lbs./ft.^{3}. Under these circumstances, it could be that social and other factors combine to increase the metabolic rate above levels otherwise to be expected. American work (Anon., 1947) has provided some evidence to show that if experimental tanks of trout fry are reared under identical conditions but at different stocking densities, there is an inverse correlation between specific growth rate and stocking density over the first four months of feeding.

There has been no other critical investigation of the influence of rearing volume on growth and conversion efficiency under conditions of intensive culture. Figure 31 (after Mayo, 1971) represents usual practice among salmonid hatcherymen in the U.S.A.

Since adequate information on the necessary water flows for higher densities is not currently available, it would be advisable for trout farmers wishing to operate in this manner, to have artificial aeration facilities available, and if possible to utilise some form of continuous monitor for dissolved Oxygen levels throughout the system. Even in order to utilise Liao's model at densities less than 2 lbs./ft^3, it is obviously necessary to make frequent daily checks of water temperature and, if possible, dissolved Oxygen concentration

FIGURE 31

Diagram to indicate the required rearing volume for salmonids, considered acceptable for various stocking rates and fish weights, under American raceway conditions; after Mayo (1971).

Y = Stocking rate (lbs./ft^3 of water)

X = Weight per fish (lbs.)

The diagram assumes that dissolved oxygen levels and water temperature are within the acceptable ranges. The thick line indicates the border above which the rearing volume is considered seriously detrimental and below which it is considered acceptable.

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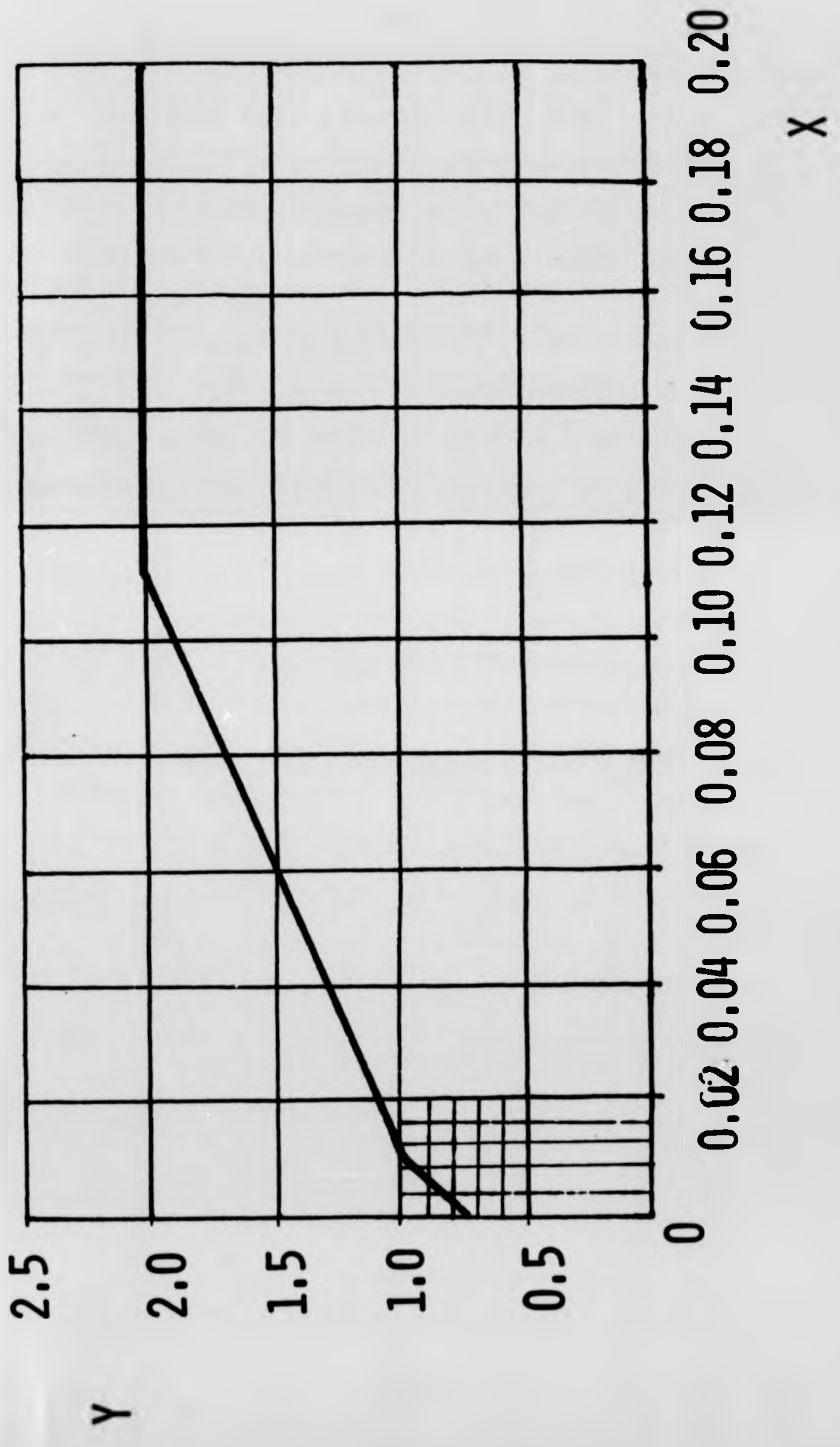
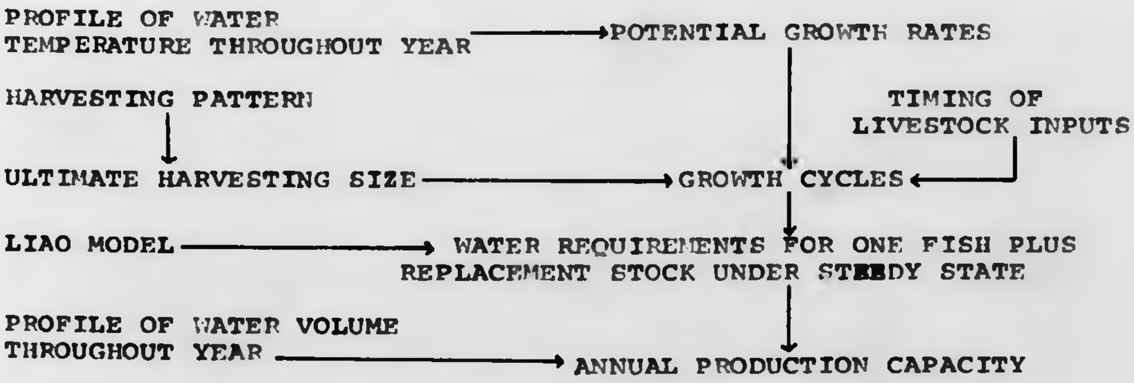


at the inlet to the system, as well as having an accurate means of computing and adjusting water flow rates. In new site evaluation, detailed investigations must attempt to establish the minimum recorded water flow rates available for use in trout culture, as well as the average yearly range for the site in question.

In order to make an assessment of the production capacity of a site, more information is required than simply the water availability and a knowledge of water requirements. Water temperature is a critical factor because of its affect on growth rate. However, other variables must be considered including some which derive from management decisions. Fig. 32 summarizes the factors involved in determination of annual production capacity and these will be examined more closely.

FIGURE 32 - Scheme for evaluation of the capacity of a site



6.3 Theoretical aspects

In site evaluation, investigations should seek to establish the nature of the seasonal fluctuations in water temperature at the site. The more constant the temperature regime, the easier it should be to predict the growth pattern over time, other things being equal; ground water from springs frequently retains a fairly constant temperature throughout the year. The use of sea water for all or part of the growth cycle is discussed separately.

It has not as yet proved possible to devise a trout culture system which is maintained in a steady state. Such a system would require constant water temperature and a constant supply of eggs. In order to predict the annual production capacity of a site, one may assume a steady state in order to simplify the problem in the first analysis.

To illustrate the prediction of site capacity for trout culture, one may postulate a fresh water resource sited at sea level at a constant temperature of 14°C, with a cycle time for trout, which are harvested at ½lb., of 55 weeks. Let us assume that harvesting takes place at intervals of five weeks, influent water is fully saturated with Oxygen and the minimum level of dissolved Oxygen permitted is 5 mg./l. If fed on Trouw pellets, the pattern of liveweight gain over time would probably be similar to that in Fig. 33 (see Chapter 7).

For a steady state to be achieved, at any one harvest, there would need to be a pattern of replacement stock as also indicated in Fig. 33, assuming zero mortality. Thus, if one fish was being harvested at 0.5 lbs., there would need to be

FIGURE 33

Diagram to indicate the pattern of liveweight gain over time for rainbow trout reared at a constant temperature of 14°C. This is based upon data obtained experimentally by Trouw and Co. for a sample of trout fed on Trouvit.

Y = Liveweight per fish (g.)
X = Age (weeks)

Values in italics within the axes refer to the time-series liveweights recorded at intervals of 5 weeks from 5 weeks of age (0.5 g.) until 55 weeks (227g.).

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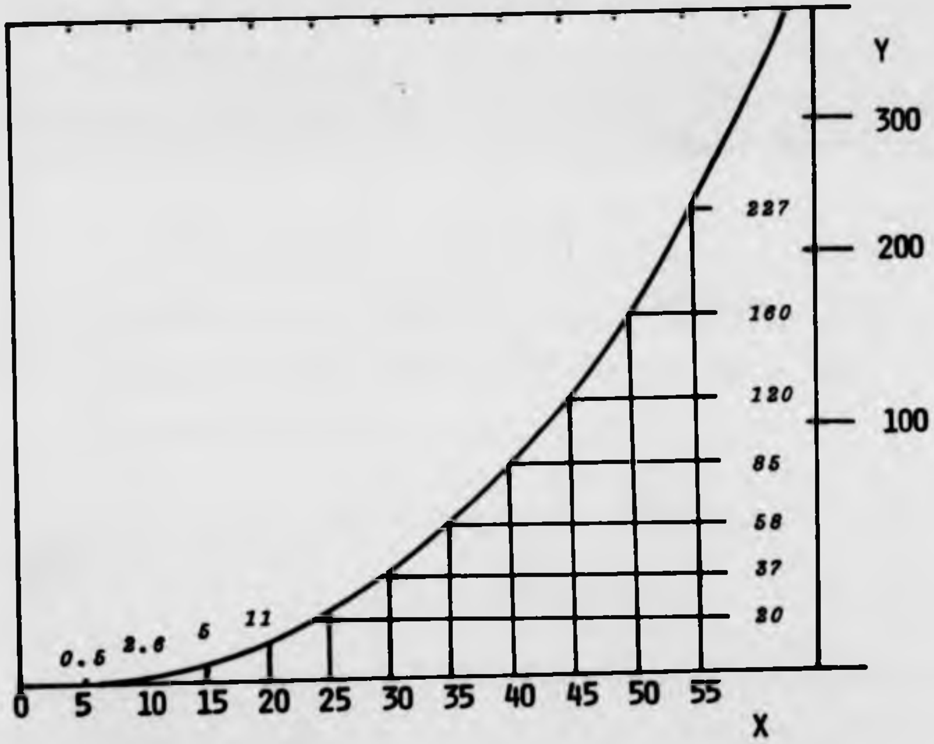

simultaneous carriage of one of each of the following replacements: 0.352, 0.264, 0.187, 0.128, 0.082, 0.044, 0.024, 0.011, 0.006 and 0.001 lbs. The Oxygen and hence water requirements, under the stated conditions, of each of these fish may be computed by Liao's method (See section 6.2,). The results are tabulated (Table 18). The sum of the water requirements for the 11 sizes of individual fish is 0.1352 g.p.m. If 1 ton of fish are being harvested every five weeks, the water requirement for the total biomass (i.e. including replacement stock) would be 0.1352 x 2240 (lbs./ton) x 2 (fish/lb.) = ca. 606 g.p.m., i.e. under these circumstances 606 g.p.m. will support a production of 11.4 crops p.a. at 1 ton with a production cycle of 55 weeks. Hence, if it was desired to produce 1 ton p.a. under the same conditions, the required flow rate would be 606/11.4 = 53 g.p.m. In a steady state situation, it may be stated that:

$$\text{Annual production capacity (no. of fish achieving market weight p.a.)} = \frac{\text{Minimum drought flow}}{\text{Water requirement/ marketable fish plus replacements}} \times \text{Harvest Frequency (no. of harvests p.a.)}$$

As the harvesting frequency increases, the production capacity of the site, for a given water flow, approaches a constant value which represents the most efficient use of the water. This may be compared with the water requirements for one harvest p.a.; e.g. if it was desired to produce 1 ton p.a. at one harvest, there would need to be sufficient water for the carriage of 1 ton of marketable fish, which (Table 18, column IV) = 0.0384 (g.p.m.) x 2240 (lbs./ton) x 2 (fish/lb.) = 172 g.p.m. The production capacity is thus dependent upon

TABLE 18

Steady state Water Requirements

I Weight/fish (lbs)	II Oxygen consumption (lbs Oxygen/ 100 lbs fish/day	III Weight of fish/ unit waterflow (lbs/g.p.m.)	IV Waterflow per fish (g.p.m.)
0.500	0.611	13.033	0.0384
0.352	0.641	12.424	0.0283
0.264	0.667	11.940	0.0221
0.187	0.699	11.392	0.0164
0.128	0.737	10.805	0.0119
0.082	0.784	10.158	0.0081
0.044	0.854	9.325	0.0047
0.024	0.929	8.572	0.0028
0.011	1.035	7.694	0.0014
0.006	1.124	7.086	0.0009
0.001	1.440	5.530	0.0002

N.B. Column II is calculated from the formula:

$$C_2 = 3.05 \times 10^{-4} \times T^{1.855} \times W^{-0.138}$$, where $T = 57.2^\circ F$ (14°C) and W is taken from Column I.

Column III is calculated from the formulae:

$$Ce = \frac{S \times 132}{T^{0.625}} \times \frac{760}{760 + \frac{E}{32.8}} \; ; \quad Q = \frac{Ce - C}{O_2}$$

where $S = 1$, $E = 0$, $T = 57.2^\circ F$ (14°C) and O_2 is taken from Column II. Column IV = Column I/Column III and its sum = 0.1352. g.p.m.; all symbols after Liao (<u>loc. cit.</u>).

the harvesting frequency under steady state conditions and the shape of this relationship is shown graphically in Fig. 34 for a constant waterflow. It is not necessarily the best strategy for a trout farmer to maximize harvest frequency since market considerations often discourage small continuous sales. Moreover, if fluctuations in water volume occur and these are predictable, then fewer harvests/cycle might under certain circumstances use the water resources more effectively, and it should be possible to programme production possibilities at the site as they vary throughout the year.

6.4 Practical Aspects

In practice in Scotland, trout farmers are unable to arrive at the conditions for a steady state because of certain factors, including:-

(i) egg production is seasonal

(ii) temperature and water flows exhibit fluctuation

(iii) some market parameters may fluctuate (e.g. there may be price rises during the winter in the U.K.).

It is possible to even out the fluctuations in supply of market size fish at Scottish trout farms by certain methods, e.g.

(i) buying-in trout eggs from the southern hemisphere in order to supplement the natural winter hatch by a summer hatch of imported eggs

(ii) genetic selection of brood fish for early and late spawning

(iii) grading a particular age group into weight classes

(iv) differential feeding regimes (e.g. Bumgarner, 1971).

(v) differential heating of hatchery water (Bulleid, 1971)

(vi) freezing the product and storing

In these ways, substantial shortfalls are not generally a problem except when freezing of the ponds prevents removal

TABLE 19

Steady state Production Capacity

I Harvest frequency (number of harvests p.a.)	II Water requirements per marketable fish + replacements (g.p.m.)	III Production of marketable fish per harvest	IV Annual production capacity
1	0.038	3.5	3.5
2	0.048 *	2.8	5.6
5	0.079	1.7	8.6
10	0.135	1.0	10.0

A constant waterflow of 0.1352 g.p.m., and water temperature of $14^{\circ}C$ is assumed. This table is calculated from the formula: Annual production capacity = Harvesting Frequency x Minimum drought flow/water requirements per marketable fish and replacement stock.

Column II is calculated from Table 18; Column III = 0.1352/ Column II. Column IV = Column I x Column III.

* is simplified to the sum of the water requirements of 1 fish at 0.5 lb., and the mean of those of 1 fish at 0.128 lb. and 0.082 lb. i.e. $(0.0384 + \frac{0.0119 + 0.0081}{2})$

FIGURE 34

The relationship between annual production capacity of a trout farm and the frequency of harvesting. This assumes steady state production with a constant flowrate and temperature for the water supply of 0.1352 g.p.m. and 14°C respectively.

Y = Annual production capacity (tons)

X = The number of harvests per annum.

$Y = 1.46^{X}/3.46$

$r = 0.99$ $p < 0.01$ – 1%

The data is derived from a theoretical consideration of steady state production capacity (Table 19) and is based upon the same assumptions.

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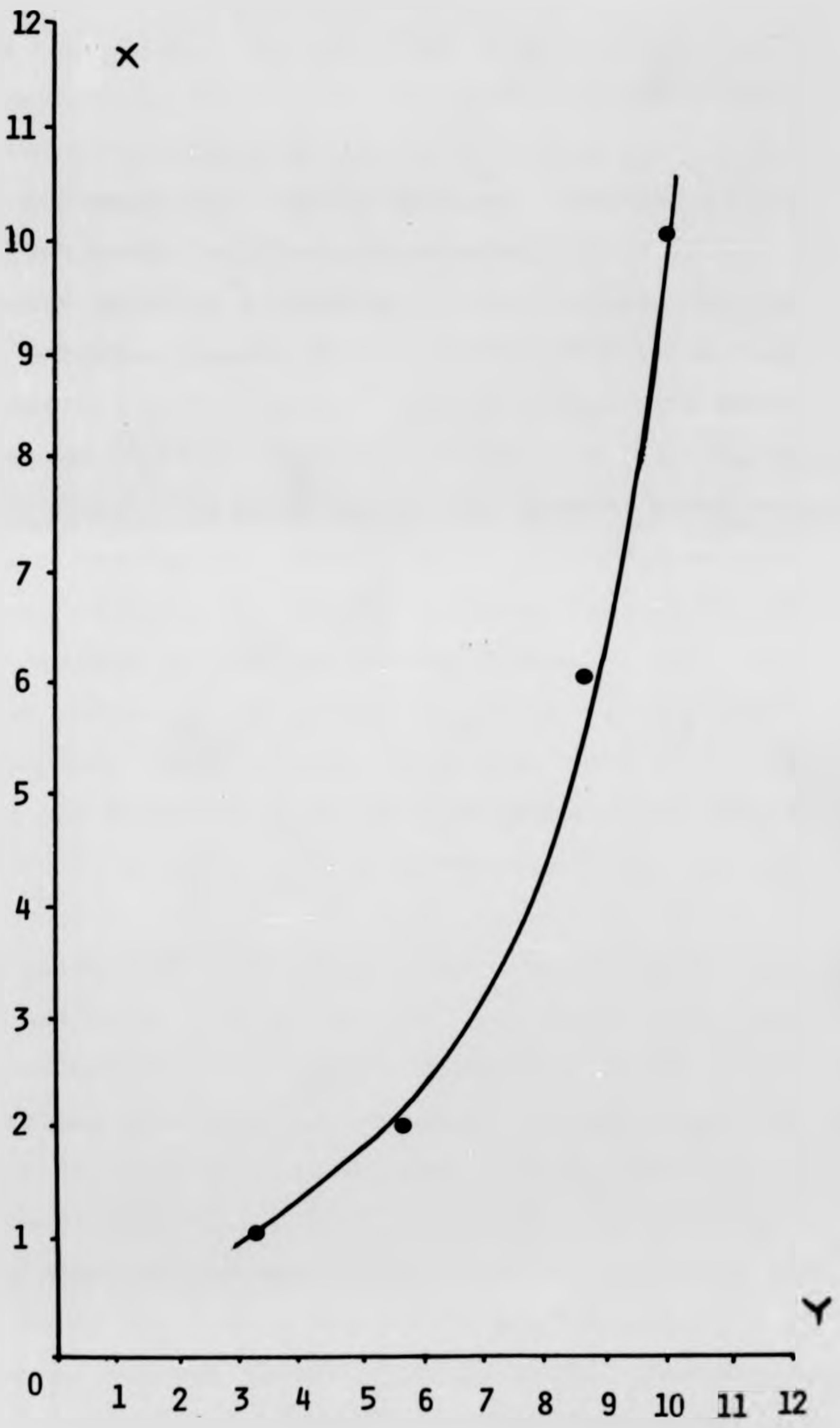

of marketable fish. If the cycle time at a farm is 18 months, the diagram (Fig. 35) shows the potential shortfalls which need to be avoided or minimized (notably during the Spring if there is both a Summer and a Winter hatch). Another complication which often occurs with Scottish watercourses is the marked constraints on water volume and higher temperatures (and hence reduced carrying capacity) which approximately coincide with the summer production peak. Certain farms with marked seasonal fluctuations in these parameters attempt to utilise the Spring and early Summer (and/or Autumn) for much of their annual production and stock a relatively low mass during mid-Summer. Thus it is possible to achieve an annual production which is not constrained by minimum drought flows.

Such variations in growth cycle and annual growth profile partly explain the disparity between various 'rules of thumb' employed for estimation of flow requirements in relation to annual production (c.f. value of 53 g.p.m. per ton p.a. in above example). Shorthouse (1972) quoted a figure of 0.2 million galls./day (139 g.p.m.) and Sedgwick (personal communication) estimated 1 gall./sec (60 g.p.m.) in order to give annual productions of 1 ton of marketable trout. The former was referring to single use of water through round fibreglass tanks and the latter to earth pond systems where the outlet canal was stocked in addition to ponds. Differences in carrying capacity per unit water flow for different husbandry systems using the same water source may be largely explained by differing degrees of water utilisation. Raceways permit multiple reuse of water (until dissolved Oxygen has been

FIGURE 35

A diagram to indicate the nature of the annual temperature cycle for a Scottish freshwater lake (Loch Morar) and its possible influence on the duration of the production cycle for rainbow trout.

Y^1 = Mean water temperature per month (°C)

Y = Stylised representation of the relative numbers of trout reaching marketable weight.

X = Time (months) over a 2 year period.

Data on the cycle of water temperatures at Loch Morar is derived from Macfarlane (personal communication) and reproduced in Appendix III. If it is assumed that eggs hatch biannually in August and February (represented by solid triangular symbols), then the largest consequent monthly harvests will occur approximately 1½ years later in the months of January and August respectively, i.e. 17 months later (solid semicircular symbol) and 18 months later (stippled symbol). The lower half of the diagram represents the approximate availability of marketable fish under conditions of regular harvesting; it is not intended to describe the precise form of the distribution.

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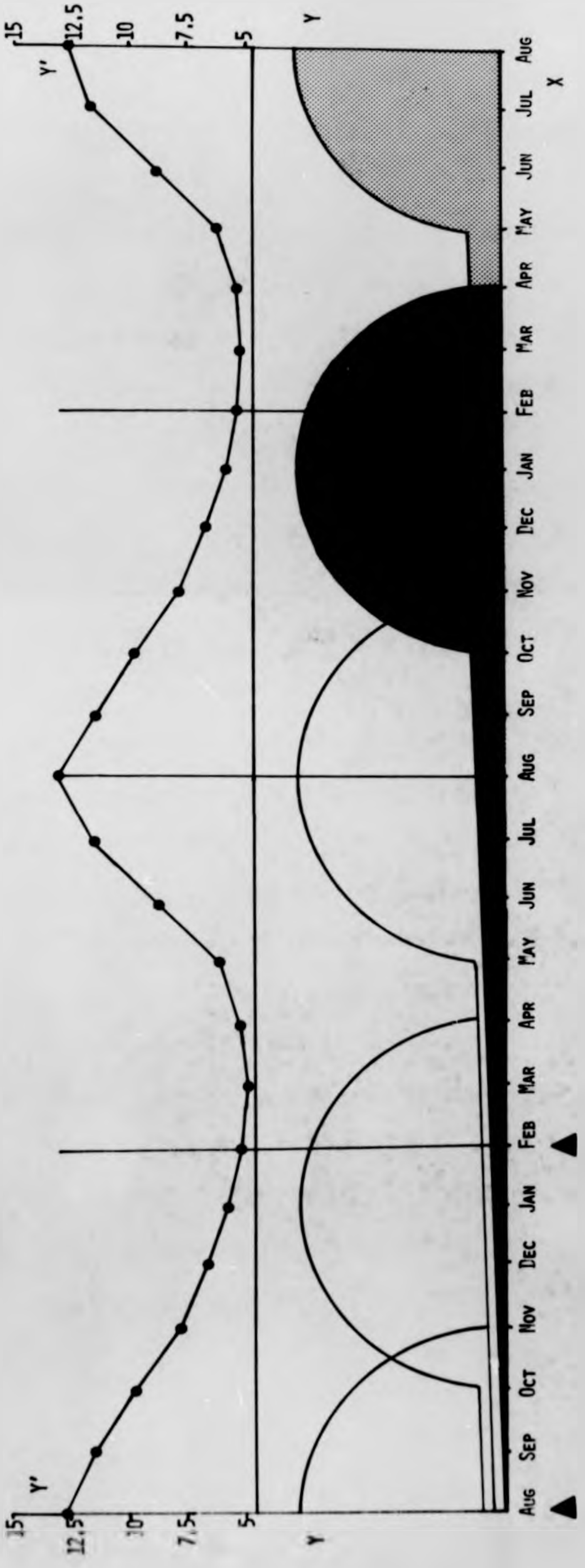

removed or toxic substances have accumulated to a level incompatible with acceptable fish growth) whereas fast flow rates through tanks (e.g. fibreglass round tanks) without reuse are likely to result in relatively less economical use of water.

With the possible exception of those systems whose design prevents easy harvesting (e.g. extensive systems, floating nets, enclosures, etc.) it is unlikely that differences in husbandry system will cause a difference in the ratio of Carrying capacity : Production capacity for a given site. This ratio is mainly dependent upon exogenous variables (availability of eggs, variations in water temperature, etc.) which determine the ability of the trout farmer to achieve a steady state production. In U.S. trout hatcheries where the cycle time is ca. 18 months, this ratio is commonly ca. 1 : 1.6 (i.e. a hatchery whose maximal stocking capacity is 100 tons can produce 160 tons p.a.) and Macfarlane (personal communication) has reported success in applying it to trout production at two sites in Scotland for the purpose of predicting required rearing volume, etc. In the example on page 97, the water requirements for carriage of 1 ton of fish at ½ lb. and for steady state annual production of 1 ton of fish at ½ lb. were 172 g.p.m. and 53 g.p.m. respectively, i.e. in this case the theoretical maximum ratio attainable was 1 : 172/53 = 1 : 3.25. In Table 20, average carrying capacities are given for different husbandry systems (based on data derived from three Scottish farms: Gateway, West Argyll, Kenmure Fisheries, Howietoun and Northern Fisheries) and annual production capacity is predicted assuming a production ratio of 1 : 1.6.

Table 20 Characteristics and carrying capacities of different husbandry systems for Trout culture

System	Av. flow rate (g.p.m.)	Av. Carrying Capacity (tons @ ½lb.)	Av. Production Capacity (tons @ ½lb.)	Carrying Capacity (g.p.m./ton @ ½lb.)	Production Capacity (g.p.m./ton @ ½lb.)
Single raceway*	350	1.75 (3.92)	2.8	200	125
2 Raceways in series	350	3.25 (3.36)	5.2	108	67
3 Raceways in series	350	4.50 (2.80)	7.2	78	49
Single earth pond+	175	2.23 (0.38)	3.6	79	49
Earth pond and outlet channel	175	2.5 (0.33)	4.0	70	44
Fibreglass round tank	150	1.0 (3.17)	1.6	150	94

* Vol. of each raceway = 1000 ft.^{3}; water exchange rate = 3/hour

\+ Vol. of earth pond = ca. 15,000 ft.^{3} (outlet channel contribution unknown); water exchange rate = 4.5/day.

*+ Vol. of fibreglass tank = 707 ft.^{3}; water exchange rate = 3/hour.

N.B. Values in parentheses in Column III (Av. Carrying Capacity) refer to the corresponding annual production per rearing unit (e.g. for 1 raceway of a series of 3), assuming a production ratio of 1 : 1.6

On the basis of this comparison, earth ponds appear similar to (3) raceways in series which appear nearly twice as efficient as single fibreglass tanks in terms of water utilisation (g.p.m./ton). It might be expected that raceways would be more efficient than earth ponds since the fabric of the latter imposes a B.O.D., and there are more areas of poor circulation etc.; some American raceways have up to 10 ponds in series (Macfarlane, personal communication) and in such cases would probably be more efficient than earth ponds at the same site. Similarly, it is probable that more than one fibreglass round tank could be placed in series to increase the productivity per unit waterflow. Robinson and Vernesoni (1969) describe a series of three (20' diam.) round concrete tanks fed by 50 g.p.m. and producing 1000 lbs. trout/pond p.a. = 1.34 tons p.a. total i.e. production capacity of *ca.* 37 g.p.m./ton which is in excess of that commonly achieved in Scotland. It may be concluded that trout production per unit waterflow is unlikely to show great variation between different husbandry systems using the same water source, provided that maximal use is made of the water. However, the use of aerators and/or recirculation devices is likely to enhance the carrying and production capacities of water, particularly under conditions of intensive culture where considerable water reuse is practised. Nevertheless, assuming the conditions stated in the Table (i.e. carrying capacities), the productions ratios implicit in the 'rules of thumb' (*loc. cit*) given by Sedgwick (earth ponds) and Shorthouse (fibreglass tanks) are respectively 1 : 79/60 = 1 : 1.32 and 1 : 150/139 = 1 : 1.08. Thus more information is required on the range of production ratios to be expected under Scottish conditions which vary at least from 1 : 1.08 - 1 : 1.6 and may vary between different years at one site. Such information is required at the planning stage in order to ascertain the size of production facility to be constructed; in initial evaluation, it is necessary to make an estimate of production possibilities at the site. Since (as will be shown) 15 tons p.a. may be considered as a breakeven volume of economic production, then it may be stated from the foregoing analysis that investments utilising a water flow of less than 1,000 to 1,500 g.p.m. may be unprofitable. In the absence of comprehensive records, the minimum waterflow at a site may be computed from the catchment area. According to Murphy (personal communication), the drought flow in Ireland = 0.004 ft^3/min./acre (36 galls./day/acre). This relationship might hold in some regions of Eastern Scotland (where annual rainfall is ca. 27"), but for the West of Scotland, Fasham (personal communication) estimated the drought flow would be 50 galls./day/acre where annual rainfall is 40" - 50", excluding areas of bare rock.

For emergency water requirements under rapidly changing circumstances, e.g. during drought conditions, other methods may be indicated. Unless artificial aerators are utilised, the simplest method of reducing the Oxygen consumption of a stock of fish in a fish-farm is to lower the feeding rate. According to Stratford (personal communication) trout require 90 gm. of Oxygen to digest 1 kg. of Trouvit and the latter represents 83% of the total water requirement at 16°C. At this temperature, saturated fresh water contains 9.56 mg.O_2/l.

If the minimum permissible is 5.0 mg./l. of Oxygen, then 4.56 mg./l. may be removed. If one considers 1,000 kg. of trout at 9", at 16°C, they require 2% live weight = 20 kg. Trouvit/day, which entails an Oxygen requirement of 90 x 20,000 = 1.8 kg. Oxygen. According to Morgan (personal communication) Oxygen consumption by Rainbow trout at feeding is a function of assimilation rate which is completed by ca. 8 hours after feeding. Thus water requirement = $\frac{1.8 \times 10^{6}}{4.56 \times 8}$ = 49342 l/hr. = 181 g.p.m. for carriage of 1 ton at 9". This may be used as an approximate guide to water requirements and/or feed requirements when constrained by water flow and Oxygen availability and may be formalized for Trouvit as the following equation:-

Required waterflow (g.p.m.) =

$$\frac{0.09(\text{Kg.}O_2/\text{digest 1 kg food}) \times \text{Feed (lbs/day)} \times 0.00366(\text{l/hr - g.p.m.}) \times 1 \times 10^{-6} (\text{mg. - kg.})}{8 \text{ (hours of assimilation)} \times \text{Oxygen available (mg./l.)} \times 2.2 \text{ (kg. - lbs.)}}$$

= 18.716 (g.p.m.) x Feed (lbs./day)/Oxygen available (mg./l.)

$$\text{Feed (lbs./day)} = \frac{\text{Water flow (g.p.m.)} \times O_2 \text{ available (mg./l.)}}{18.716}$$

= 0.0535 Water Flow (g.p.m.) x Oxygen available (mg./l.)

This relationship is similar to that of Willoughby (1968) who stated that (Oa - Ob) x 0.0545 x g.p.m. = lbs. of food/day where Oa and Ob are the Oxygen contents at influent and effluent respectively (mg./l.) and g.p.m. is the influent flow rate.

Since feed guides are designed to take into account fish weight and water temperature, use of a relationship which demonstrates the effect on the system of manipulating the most critical variable (Oxygen consumption) by means of feeding rate, has simple practical significance as a short term measure. To operate this method, Oxygen measurements should be made at the influent unless the water is fully saturated (when temperature data will allow computation of dissolved Oxygen). It is likely that this method would be less satisfactory if the feed was exerting a Bio[illegible]ical Oxygen demand on the water before ingestion either because of being uneaten, e.g. with excess sinking pellets, or because of dissipation, e.g. with trash fish feeding.

6.5 Summary

The water requirements of salmonids are reviewed, and the model of Liao is selected as having particular advantages for predictive purposes. If the breakeven level for economic production of trout is 15 tons p.a., this is likely to require a flow rate of 1,000 - 1,500 g.p.m. Site evaluation should seek to ascertain the annual production capacity of sites with mean flow rates exceeding this level, assuming acceptable water quality. The water requirements for trout under the theoretical conditions of a steady state system may be calculated from a knowledge of growth characteristics for different levels of annual production and different harvesting policies. In practice, however, this is complicated by annual changes in water volume, temperature, and availability of trout eggs, which may tend towards a cyclical pattern of production. The production characteristics for various husbandry systems under Scottish conditions are considered. It may be possible to programme production so as not to be directly dependent upon minimum drought-flows. As a short term expedient, a knowledge of the Oxygen consumption per unit weight of feed may be used as a basis for manipulating water requirements when constraints are severe;

a relationship is developed for Trouw diets which is comparable to a published formula.

CHAPTER 7

NUTRITION, FEEDING AND GROWTH OF TROUT

7.1 Introduction

The main feeds utilised as trout diets are either Simple (i.e. liver, offals, minced fish, or whole fish) or Compound (i.e. moist pellets or dry pellets).

The use of Liver and Offals has been largely superseded in all but the smallest hatcheries (or as an occasional 'tonic'). Moist pellets, e.g. 'Oregon' and 'Abernathy' diets are increasingly used for the culture of Salmon but have found limited use in Rainbow trout culture (with the exception of experimental wetted pellets in salt water culture); these are well documented and comprise dietary ingredients combined with 25% or less water and a binder (Hublou et al., 1959; Fowler and Burrows, 1971).

Wet fish feeding is practised particularly in Norway and Denmark. This practice utilises minced-up sea fish and is discussed hereafter. However, British trout farms probably make exclusive use of commercially prepared pelleted diets as trout feed at the present time. These have produced increasingly satisfactory growth rates over the last decade when considerable information on the nutrient requirements of trout has become available.

7.2 Nutritional Requirements of Trout: (A Summary)

A comprehensive review of work on nutrition, digestion and energy utilisation has been presented by Phillips (1969) with special reference to trout, which have been extensively studied particularly in the U.S.A.

(i) Protein

The crude protein of the diet should be within the range: 40 - 50%, depending upon temperature and dissolved Oxygen of the water. At higher temperatures, the crude protein content may be increased to match the increase in metabolism. The protein must have a high biological value (there are at least ten essential aminoacids for trout) and those most commonly used are fish meal, beef greaves, skim-milk powder and blood meal.

(ii) Carbohydrates and Fats

The crude fibre content, being poorly digested by trout should be not more than 10% (Trouw and Co. regard the preferred range as 5 - 6%). The upper limit for other carbohydrates is <u>ca</u>. 30%. The energy component of a ration for trout is represented by the carbohydrate and fat fractions.

Fats are required by trout both as sources of essential fatty acids and as an energy source. If the fat content of the diet is increased above 5%, then the increase in energy should be balanced by an increase in crude protein. A common preferred ratio for crude protein : energy is 65 : 70, and the fats utilised for the energy component should be of a low melting point.

(iii)Minerals

The minerals generally added to a diet for trout are Calcium, Phosphorus, Magnesium and Sodium Chloride. Trace quantities of Iron, Manganese, Zinc, Copper, Cobalt, Iodine and Selenium are also added although it is preferable to assess the amounts of these substances naturally present in the water of the trout farm, before computing the quantity to be incorporated into the feed.

(iv) Vitamins

Supplementation with those vitamins which are insoluble in water, i.e. Vitamins A, D, E and K, is particularly essential for trout. Requirements have been established for Vitamins B_1, B_2, B_6, B_{12}, pantothenic acid, folic acid, choline. Although the stringency of their requirements is not fully understood, some manufacturers also add Vitamin C, tricotinic acid, Inositol and para-amino-benzoic acid.

7.3 Dry Pellet Feeding

The confidential details of the second most popular diet for trout culture in the U.K. are included as Appendix IV describing gross analysis, particle size and the master formulation for Trouvit. The result of an experiment performed by the manufacturers using this diet is reproduced (Fig. 36). Details of the experimental design (e.g. stocking densities and population size) are not available; neither are details of the mortalities occurring, if any. Of interest to the fish culturist are certain characteristics shown in this figure, notably:

i) the pattern of live weight gain over time,
ii) the pattern of food consumption over time,
iii) the pattern of feed conversion over time,
iv) the pattern of feed types needed by trout.

Rainbow trout are usually marketed in the U.K. at a live weight of ca. 200 gms (6 - 8 oz.). Under the conditions of this particular experiment (constant water temperature of 14°C), a time of 50-55 weeks was required to achieve market weight of ca. 200 gms. from swim up (when feeding commenced). At 53 weeks, the individual fish had consumed ca. 260 gms. (ca. 9 oz.) of six (consecutive) trout feeds (i.e. of various particle sizes and compositions).

FIGURE 36

Diagram to indicate the pattern of liveweight gain, food consumption and food conversion rate for one rainbow trout reared from swim-up to an age of 80 weeks. This is based upon data obtained experimentally by Trouw and Co. for a sample of trout held at a constant water temperature of 14°C., and fed with seven sizes of Trouvit pellets, as indicated.

Y = Cumulative food consumption (g.) = graph FC (Y)
Y^1= Cumulative liveweight gain (g.) = graph LWG (Y^1)
Y^{11}= Cumulative food conversion rate (Y/Y^1) = graph FCR (Y^{11})
X = Age (weeks)

Data presented represent mean values recorded for a sample of unknown size.

Broken line indicates duration of feeding of each of the seven sizes of Trouvit pellets used -
Trouvit Nos. 00, 0, I, II, III, IV and V.

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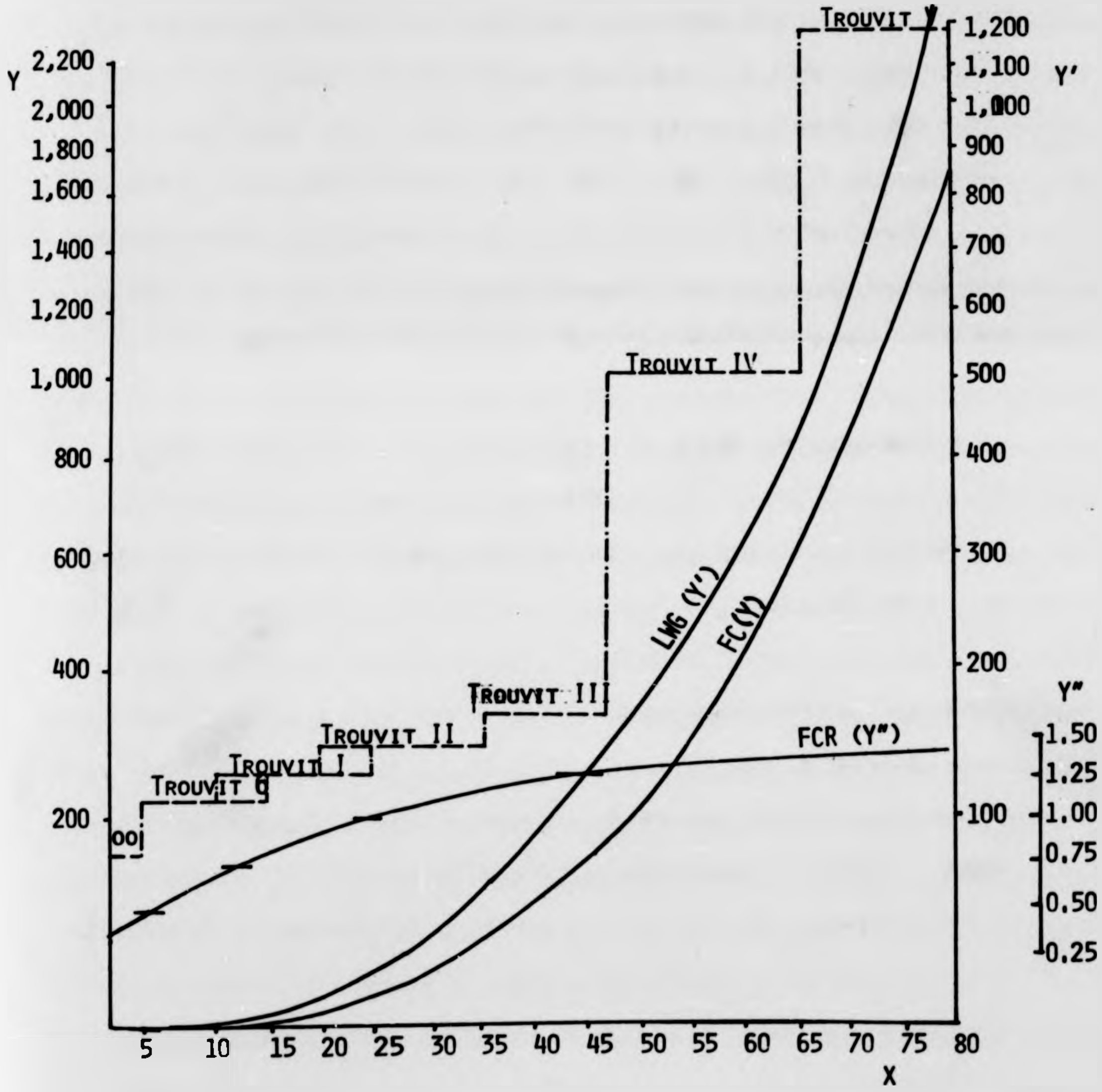

7.3.1 Theoretical aspects

The conversion of food to growth introduces the concept of efficiency. Food consumed in excess of the maintenance requirements is converted *pro rata* into growth; feeding below the maintenance level leads to loss of weight. The conversion efficiency may be expressed mathematically as follows (Birkett, 1972) : the simple or net efficiency, E, is W/I, where W = net body gain and I = total food intake. The *pro rata* or gross efficiency, E*, is $W/(I - Im)$ where Im = maintenance requirement.

In the experiment aforementioned, the ratio of total net liveweight gain : total food intake at the time of marketing was 200 : 260. According to the graph, the Food Conversion Rate (FCR) at this stage was *ca*. 1.3, i.e. the trout required *ca*. 1.3 units of feed in order to gain an increment in liveweight of 1 unit. The efficiency of feed conversion is the reciprocal of food conversion rate = $^1/1.3$ = 0.77, and it will be observed that trout, which convert with extreme efficiency when small fry, exhibit a rapid reduction in this parameter from values of *ca*. 2.0 at a liveweight of 0.5 gms. to values of *ca*. 0.77 at 230 gms. liveweight, by which time the rate of reduction in efficiency has slowed considerably. The gross efficiency appears to approach a constant value until gametogenesis commences when a check is usually observed.

Food conversion rate is a concept of considerable significance to the fish culturist, who is interested in the valuable output which he wishes to maximize at minimum cost to himself. However, some confusion has arisen with the use of this concept for several reasons. Thus it may be misleading if used without:

i) reference to the particular range of fish weight under consideration. A F.C.R. of 1.3 would be very satisfactory in commercial trout farming up to 200 gms., but not if recorded up to only 20 gms. liveweight.

ii) reference to mortality or loss in the population, should this have occurred.

iii) reference to the nature of the diet used and particularly its moisture content. Thus a F.C.R. of 5.5, unsatisfactory for a commercial pelleted diet with a moisture content of 5 - 10%, would be satisfactory if it referred to a diet of wet fish, offals, etc. having a moisture content of 70 - 80%, thus being comparable to a F.C.R. computed on a dry weight basis of 0.3 x 5.5 = 1.65. (This problem explains how it is possible to achieve F.C.R.'s of less than unity, since when feeding dry pellets to young fish, the latter have a greater moisture content than their feed).

In commercial trout production, if the goal is simply to maximize sales, then the trout farmer would attempt to maximize growth. However, this might result in a poor conversion efficiency (e.g. Paloheimo and Dickie, 1966) and, since feed costs usually comprise the largest element of operating cost, the cost of such a procedure is likely to be prohibitive. In practice, therefore, most trout farmers adopt a compromise in order to obtain fast growth rates and satisfactory conversion efficiencies. The procedure adopted at a particular farm is usually based on one or more of the following methods:

i) the use of feeding tables

ii) permitting fish to feed until satisfied.

iii) adopting a feeding regime for the fish which continues until the 'edge goes off their appetite'.

The choice between these alternatives is dictated partly by the technique used for administering the feed, which in turn may be influenced by the nature of the site, the husbandry system used, and the types of feed available.

Until recently a theoretical framework for considering these problems had been lacking. However, recent Japanese work has explored some of the characteristics of food consumption for Rainbow trout held under experimental conditions and this work has been reviewed by Ishiwata (1970). After acclimatisation has been achieved, the quantity of food required to satiate an experimental school of fish in a single feeding ('satiation amount') may be used as an indication of food consumption. As the period of food deprivation increases, the satiation amount first increases and then levels off to a constant value. Other factors found to increase the satiation amount include:

i) palatability of feed
ii) water temperature (within a moderate range)
iii) percentage of dissolved Oxygen
iv) unit weight of fish (as body weight increases, satiation value increases proportionately; however, the ratio of satiation amount : body weight declines).

One relationship between the daily rate of feeding (mean ration per day/body weight), f, and the daily rate of growth (mean increase in weight per day/body weight), g, has been expressed by the formula $g = af-b$. The amount of food required to maintain 1 gm. of body weight/day is calculated from this and, when $g = 0$, for Rainbow trout fed on a compound diet, the maintenance requirement was 9.4 mg. at $12.4^{\circ}C$;

at *ca.* 10°C, it was only 4.0 and 4.3 mg. for trout at live-weights of 83.9 gm . and 15.1 gm. respectively (Ishiwata, *loc. cit.* In previous studies, the same author (Ishiwata, 1969) had demonstrated that, as the daily rate of feeding increases, the daily rate of growth increases approximately in proportion. However, if the daily rate of feeding is increased, the efficiency of food conversion (daily rate of growth/daily rate of feeding) does not increase proportionately but increases so as to approach a maximum value. It is therefore suggested that a frequency of feeding in excess of 2 - 3 times per day will be of very little advantage (since this frequency range coincides with 90% of the maximum value for daily rate of growth in Ishiwata's experiments on Rainbow trout at 12°C.).

7.3.2. Practical aspects

It is hoped that further work might establish the relationship, if any, between food conversion efficiency and degree of satiation. A recent development in trout husbandry has been the introduction of self-feeders (demand feeders) which are triggered by the fish as required. It is alleged by some trout farmers that such devices are wasteful of feed as the fish on occasion appear to 'play' with the pendulum trigger and release food which is left uneaten. They are certainly far more economical in labour and possibly produce a deeper - bodied fish than is the case with hand-feeding (Shorthouse, personal communication). Against these advantages, must be placed the inability to use such feeders in heavily-stocked raceways with fast flow rates (Fairweather, personal communication) and the restriction of their use to dry pelleted diets, as well as the tendency for some models to have operational problems (particularly becoming clogged and sticking due to water entering the exit pipe). One trout farmer interviewed (Muller, personal communication) explained that he found self-feeders most satisfactory at low temperatures when fish were not feeding very much; when the water temperature exceeded *ca*. 6°C., he replaced his self-feeders by automatic feeders. The latter are commonly in use for fry tanks and are increasingly used for larger trout. The most popular design utilises a compressed air pipeline which ejects a predetermined weight of pellets at time intervals dictated by electrical time switch-gear. The main rationale for the use of such equipment for fry has always been the belief among hatcherymen that growth rates and conversion efficiencies are higher if the fish are fed 'a small amount, often' each day, than if they receive their total daily ration in 1 or 2 feeds only. This view is challenged on biological grounds by the experimental work described (Ishiwata, *loc. cit.*) and also by some practising trout farmers (Dessan-Arp, personal communication), and the potential for reduced labour costs may provide a more logical rationale for such automatic feeding. A disadvantage of automatic feeders is the restriction of their use to dry pelleted diets. The author has seen one Danish trout farm which uses a machine to deliver wet feed into trout ponds but these are costly and rather unsatisfactory (Langrad Jensen, personal communication). The most popular automatic feeders (compressed air feeders and spinning disc feeders which spray the pellets out centrifugally from the centre of the tank or pond) require a power supply, unlike self-feeders, etc. However, it is possible to utilise the waterflow in order to turn a small paddle wheel which delivers the pellets from a hopper, and thus obviate the need for a power supply.

The feeding systems described hitherto have the disadvantage that the response of the trout is not accounted for during the feeding process. Manual feeding (or manual control of an automatic feeder) permits the operator to modify the feeding process dependent upon the behaviour of the trout at feeding. Moreover, the operator is in a position to adapt the feeding regime to his knowledge of certain other factors, e.g. environmental: temperature, turbidity of the water, or operational: imminence of grading, transportation stress, which would make it desirable for the fish to receive less feed than they might otherwise take.

In the case of self-feeders and hand feeding, most hatcherymen do not use any theoretical framework for deciding the amount of trout pellets to be fed, and instead this is determined primarily by the appetite of the fish. However, in the case of automatic feeders, it is necessary to establish particular feeding levels and these are based, for the most part, on tables which relate the amount to be fed to the water temperature and fish size.

Freeman et al. (1967) criticized this method, claiming that differences in feeding practices, in hatchery layouts, and in pond construction, indicated a need for feeding levels which were related also to individual conditions in each rearing unit. They cited the different growth rates which result from varying water quality throughout a series of raceways or ponds and suggested that this called for different feeding levels in successive units of the series. An alternative system was therefore proposed, namely that calculations of feed levels be based upon expected growth. Two methods were described (i) Per cent gain and (ii) Length increment and calorie method, by Freeman et al. (loc.cit.)Both methods rely upon historical records to make predictions of growth (and, for the per cent gain method, of conversion efficiency). The more comprehensive 'Length increment and calorie' method utilises the weight/ length relationship: $W = KL^3$ (Haskell, loc. cit.) where W = total weight (lbs.); L = total length (inches) and K = condition factor (see section 7.5) which Haskell found to be 0.0004055 from experimental data on various trout species in New York State hatcheries. Using historical records of weight gain over similar months (and thus temperature regimes), predictions may be made as to future weight gains. The work of Phillips and Brockway (1959) is cited in order to advise the calorific availability to trout of the various food groups and suggestions made as to the conversion efficiencies of diets with differing calorific values. The degree of empiricism in these methods demonstrates the problems associated with providing a general model for feeding rate when the relevant variables cannot be controlled; hence the reliance upon historical models.

7.4 Wet Fish Feeding

The culture of trout using diets of fresh or frozen sea fish or fishery by-products has been attempted in the U.K. on two occasions but has since been discontinued. This method is the predominant practice in Norway and Denmark. The species of sea fish used most commonly are:

Herring (*Clupea harengus*).

Sandeel (*Ammodites spp.*). Whiting (*Merlangus merlangus*).

and Prawns (*Pandalus spp.*)

These diets are minced, but otherwise fed unprocessed and usually have a dry matter of 20 - 30% (compared with 90% or more for Trouvit pellets). The composition of certain species, notably Herring, fluctuates seasonally. The availability of other species (notably Sandeel, which is widely regarded as the best wet diet available) also fluctuates seasonally. Average body compositions of Herring, Sandeel and Whiting are given in Table 21.

The main species fed to Trout in Norway are Herring, Saithe and Prawns, where certain factors, e.g. difficulties with communications, encourage the use of freezing facilities and the frozen diets are thawed before mincing and feeding. Market considerations in Norway (unlike Denmark) also encourage the production of trout with pigmented flesh, and for this reason, it is customary to include in the diet either whole prawns or prawn-processing offals. These supply carotenoid pigments which impart a salmon-pink colour to the trout flesh. These pigments have now been successfully synthesised and are available at a premium price with commercially pelleted dry diets (being customarily fed for 1 - 3 months prior to slaughter). The fact that trout are cultured to a larger size in Norway permits the possibility of feeding whole fish in the diet and this is practised to a limited extent. The main species used is Herring and it is alleged that where these have been fed to Atlantic Salmon, it is difficult subsequently to encourage them to take a minced diet (Jensen, personal communication).

In Denmark, the main species used are Herring, Sandeel and Whiting. Daily landings are made by an industrial

TABLE 21

Average body compositions for some industrially fished species in the North Sea (% of total wet weight): After Lund (1966)

Species	Dry Matter (%)	Protein (%)	Fat (%)
Herring (Jan./April)	23	15.5	4.5
Herring (May)	26	15.5	7
Herring (July/Sept.)	39	15.5	19
Sandeel	27	16.5	5.7
Whiting	22	15	1.5

fishing fleet at the Jutland ports. The species used would otherwise be utilised mainly as fish meal for cattle feeds and in the production of Margarine, or sold unprocessed to mink farmers. Unless the fish farm is close to a port, a haulier is paid to provide a daily service of this unprocessed 'trash' fish to the farm in fibreglass bins. Each trout farm has a mincing machine which is then used to grind the fish into a pulp suitable for feeding. It has become an increasingly popular practice within the last five years to add a binder to the feed at this stage. This is produced by Skretting A/S of Stavanger, Norway and is mainly Carboxymethyl Cellulose, added usually at a concentration of 3 to 6% of the total feed. The feed is generally delivered manually to the fish and is fed on average twice each day (sometimes excepting Sundays). Conversion rates on trout farms where a high standard of husbandry is practised are usually 5.0 - 6.0 : 1 and the use of a binder is alleged to improve potential conversion rates still further. The main problems associated with wet feeding are as follows:

(i) **Bulk:** on account of the high water content, there is ca. 4 times the weight compared to the equivalent ration of dry feed, and this makes a heavy demand on labour.

(ii) **Inconvenience:** apart from the weight factor, the feed has to be minced requiring labour, power and machinery. It cannot be stored (unlike dry feeds) unless refrigerated. It cannot easily be fed automatically (unlike dry feeds) and is unpleasant to handle.

(iii) **Pollution:** there is a marked effluent problem arising from this practice. Herring imparts an oily scum to the water and also both increases the B.O.D. (thus tending to stress the fish) in the ponds, as well as pollutes the watercourse leading away from the trout farm. Dispersion, and hence pollution, is reduced by the addition of binders to the feed.

(iv) Dietary problems: some of the trash fish used have high oil contents, particularly at certain seasons. Ingestion of such fish predisposes to fatty degeneration of Salmonid livers; for this reason, some Norwegian farmers net their trash fish in the winter, when the fat content is lower, and keep it in cold store. Thus at one Norwegian Salmon farm, Bdr. Grøntvedt at Hitra, of a total of 11,500 fish planted out in cages during Spring, 1971, only 1,600 were alive at the end of the Summer; the remainder were all thought to have died with hepatic degeneration due to Herring feeding (Sim, personal communication). Another problem is due to the high levels of Thiaminase in certain trash fish (notably Herring), which necessitates the addition to the feed of Vitamin B_1 under certain conditions. By contrast, the composition of a pelleted diet is known and is generally kept stable (e.g. Crude protein content of most growers' pellets is *ca.* 45% whereas it may vary from 15 - 20% for trash fish).

7.5 Trout growth

The metabolism of fish is directly correlated with water temperature (see Chapter 4), and optimum temperatures for growth of Rainbow trout are probably in the region of 16°C. If Rainbow trout are held at a constant temperature of 18°C, they may eat more and grow more quickly than at 16°C, but their food conversion efficiency will probably be unsatisfactory; and they may be more prone to disease etc., since they will be in an environment with a little less dissolved Oxygen and could thus be more stressed than at 16°C. At temperatures less than 16°C, they will eat less food and grow less quickly although the food conversion efficiency could be comparable with or even exceed that at 16°C.

There is a lack of data on the effect of temperature on the growth of Rainbow trout. It has been shown that a relationship exists between specific growth rate and both water temperature and diet (section 7.3.1). Kato and Sakamoto (1969) have shown that the practice of grading trout into different weight classes influences growth rate (thus, if a given age group are separated into two subgroups on the basis of unit weight, the heavier fish will grow more quickly than those in the lighter subgroup). The possible influences of light/darkness periodicity and season have also been cited. One unconfirmed report (Campbell, 1969) has alleged that Brook Trout maintained in constant light grew at a rate up to 25% higher than similar batches kept in constant darkness and in simulated daylight. It is also probably possible to reduce the growth constraint imposed by sexual maturation by chemically interfering with gametogenesis, e.g. by the use of Cobalt 60.

Bulleid (1972) has shown that the incubation of eyed Rainbow trout ova in fresh water at temperatures of between 3.75°C and 8.75°C above ambient resulted in the ova hatching 13 days in advance of those at ambient temperature and in the resulting alevins commencing to feed 27 days earlier. Some authors, for example Hickling (1963), have recommended the use of heated water, as in warmed power station effluents, in order to enhance the growth rates of Rainbow Trout. Results of such experiments, if they have been performed under conditions of intensive culture, are not in the literature. Different feeding regimes and the complications arising from non-standardization of culture system and genetic strain would make any such results difficult to apply to a variety of different intensive culture units. Thus most discussion on the potential of a body of water with a particular temperature regime for growth of trout utilises the work of Haskell & Wolf (1956). These workers collected growth data on 16 lots of Brook trout from a single original source. Two lots were assigned to each of eight hatcheries and reared under controlled conditions from a size of 1½" to one of 4¾", and it was demonstrated that, at a given temperature, approximately the same number of days was required for each one-half inch of growth. Haskell's theory of trout growth essentially stated that the increase in length of immature trout is the same, regardless of size, if the fish are held under comparable conditions, e.g. a 2 inch fish and a 5 inch fish will increase in length by the same amount in the same length of time if kept under comparable conditions. In the same work, Haskell stated that the weight and length of trout are related by the equation: $W = KL^3$ where W = total weight (lbs.); L = total length (inches); K = condition factor. These relationships were then used to develop a series of tables. Thus a table was presented showing growth rates for Brook trout from 1½" to 6" in length as computed for water temperatures of 40°F, 42°F, 44°F, 46°F, 48°F, 50°F, 52°F and 54°F (i.e. 4.4°C, 5.6°C, 6.7°C, 7.8°C, 8.9°C, 10.0°C, 11.1°C, 12.2°C respectively). There are considerable dangers inherent in adapting such data for Rainbow trout being cultured to table size (e.g. 10") under intensive conditions. One of the largest problems involved in even testing whether such a comparison might be valid, arises from our ignorance of the weight distribution in a population of trout (Rainbow or Brook) and how this varies over time. It may safely be assumed that the variation in unit weight of a batch of trout under intensive culture will increase with age, but there is an absence of data on the shape of the distribution and how it alters with age. Despite these drawbacks, empirical use of Haskell's data in planning Rainbow trout culture systems has provided a reasonable guide to the average growth expectations in populations grown under raceway systems (Macfarlane, personal communication). In Appendix III, average monthly water temperatures at one fresh water loch (Table 22) have been used to predict potential monthly length gains for trout and hence predict monthly weight gains per 1000 fish stocked at 1" on the 1st of each month from December to June. These tables, which are computed using the growth model of Haskell & Wolf(loc.cit.)indicate that trout

Table 22: Prediction of trout length and weight using Haskell formula, from mean monthly water temperatures, Loch Ness

Month	Water Temp. (°F)	Daily length gain (inches)	Monthly* length gain (inches)
January	42.5	0.0090	0.279
February	41.5	0.0069	0.193
March	41.0	0.0029	0.090
April	41.5	0.0069	0.207
May	43.0	0.0090	0.279
June	48.0	0.0193	0.579
July	53.0	0.0297	0.920
August	55.0	0.0359	1.112
September	52.5	0.0297	0.890
October	49.5	0.0234	0.725
November	46.0	0.0152	0.456
December	44.0	0.0111	0.344

* Note: Projections from 1st of Month

Temperature data after I.S. Macfarlane (personal communication) whose mean length is 1" on 1st February at Loch Ness might achieve a mean length of 10.71" (equivalent to unit weight of ½ lb.) on 8th September the following year, when reared intensively. Similarly, fish whose mean length is 1" on 1st June might achieve a mean length of 10.71" on 6th October the following year, i.e. due to the temperature cycle at this loch, the growth cycle (from 1" to market size) commencing 1st June might be 493 days or 92 days less than that which commenced 1st February.

Trout reared intensively on Trouvit at a constant temperature of 14°C have a mean growth cycle (from swim-up fry) of 55 weeks. Trout farmers in Scotland using fresh water claim an average growth cycle of ca. 78 weeks. The diagram (Fig. 37) indicates average growth cycles attainable at mean temperatures of 19°C, 14°C and 9°C. It is likely that, where fluctuations in water temperature occur, in order to maximize growth, the culturist should plan his operation so that peak temperatures coincide with the later (more exponential) part of the growth cycle; unfortunately concurrent fluctuations in water volume often prohibit this.

7.6 Summary

Considerable knowledge exists on the nutrient requirements of trout. Compounded pellets are commercially available and the patterns of liveweight gain, food consumption and food conversion obtained for Rainbow Trout fed on such diets are described, together with their implications. The factors affecting the choice of feeding method are discussed. The practice and problems of feeding wet trash fish diets are considered.

FIGURE 37

Diagram to indicate the probable relationship between the duration of the production cycle of a rainbowtrout farm and the mean water temperature.

Y = Cycle time from eyeing-up of eggs until a mean market weight of 7oz. is achieved (weeks).

X = Mean water temperature (°C)

The three plots were obtained by prediction from Haskell (loc. cit.) and by interviews with trout farmers.

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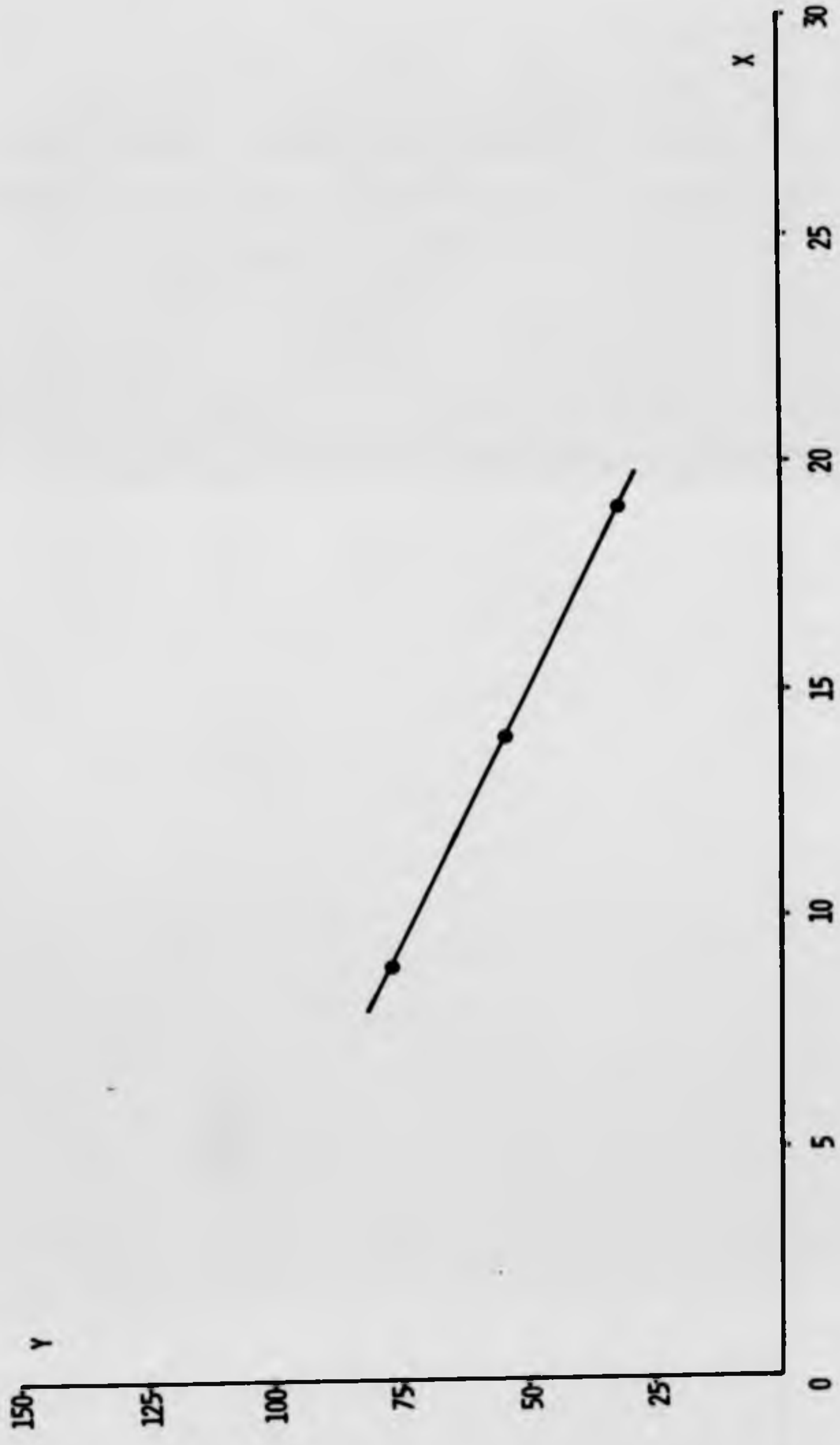


The optimum temperature for culture of Rainbow trout is ca. 10°C. Growth rate is affected by temperature, diet, grading, light, season, sexual and genetic factors, etc. The first three factors are most likely to be manipulated in the short term to enhance growth rates by the culturist. The annual water temperature profile at a site will determine the growth cycle of trout cultured there; thus water of a constant temperature offers a more easily predictable growth cycle. The length of the growth cycle (to 0.5 lbs) in Scotland is ca. 18 months.

CHAPTER 8

ECONOMICS OF TROUT FEEDING

8.1 Introduction

Trout require protein of a high biological value for growth, and for fast growth with a commercial trout diet, it has been found necessary to introduce a high proportion of fish protein into the diet. It is of considerable significance that the cost of production in trout culture is influenced by the cost of sea fish and their by-products.

8.2 Pelleted (Dry) Diets

For the above reasons, the cost of production, and hence retail price, of commercial trout pellets is influenced by the price of fish meal. The availability of the latter is determined to a significant extent by the state of the very large industrial fishery of Peru. There has recently been a shortfall in the Peruvian landings of sea fish, causing a considerable escalation of international fishmeal prices. This phenomenon has been observed before and the landings are expected to return to near-normal levels by 1974 with a consequent harmonization of fish meal prices (Mace, personal communication). The escalation in fish meal prices (ca. 100% price rise from Jan. 1972 - Jan. 1973) has coincided with, and heavily influenced, concurrent escalations in prices of other raw materials used in production of trout pellets (Table 23). Current restrictions on American exports (e.g. of Soyabean meal) may prevent or hinder any future harmonization of fish meal prices causing a similar reaction in the market for these other products.

TABLE 23

Prices paid by an animal-feeds manufacturer (Trouw U.K. Ltd.) for trout feed raw materials (Source: Stratford, pers. comm.)

Raw Material	Old Price (£/ton)	Date of Old Price	New Price (£/ton)	Date of New Price
European Herring Meal	110	June 1972	220-230	Feb. 1973
Soyabean Meal	70-80	Oct./Nov. 1972	125	Jan. 1973
Wheat ('off field')	28-29	Aug. 1972	43-45	Feb. 1973
Skim Milk powder	100	(?) 1971	260	Sept.1972

Mainly due to these raw material price rises, the retail prices of the main pelleted diets available in the U.K. (Coopers', Trouw, and Clarks') increased by 20 - 30% over the period March, 1972 - March, 1973 (Table 24). Knowledge of the conversion efficiencies attained with these diets permits computation of the cost of unit liveweight gain for trout. Under farming conditions, conversion efficiency values are likely to be poorer than the results obtained by Trouw & Co. under experimental conditions (Chapter 7). Trouw's data on feed consumption of various pellet sizes may, however, be used to establish the minimal farm feed costs likely to be incurred in rearing trout to portion size (≯ 10 oz. unit weight) (Table 25). From the summated feed cost/fish reared to 10 oz., the feed cost/ton @ 10 oz. may be calculated = (2240 (lbs/ton) x 1.6 (fish/lb.) x 0.06128 (feed cost/fish)) = £220 on Trouw (and £207 on Coopers'). From the Trouw data, it is also possible to compute feed costs/ton of fish at various unit

TABLE 24 **Retail prices of two commercial Trout diets (delivered Scotland)**

Pellet Size (or equivalent grade)	Trouw[+]: March 1973 (price (£)/metric ton)	Coopers': March 1973 (price (£)/metric ton)	Trouw[+]: Nov. 1972 (price (£)/metric ton)
00	220	241	180
0	215	241	175
1	170	181	140
2	165	148 *	136
3	160	148 *	130
4	156	148 *	126
5	150	-	116
Breeders'	170	186	130

+ Trouw's pigmented diets cost an extra £18/tonne at 'normal' levels and £72/tonne at 'high' levels

* Coopers' floating pellets cost an extra £3/tonne.

TABLE 25 Feed cost/fish fed on two pelleted diets, predicted from data on feed consumption for each pellet size (Trouw & Co. experiment)

Pellet size	Feed consumption for each pellet size/fish (gms)	Feed consumption for each pellet size/fish (lbs)	Feed cost for each pellet size/fish on Trouw (£)	Feed cost for each pellet size/fish on Coopers' (£)
00	0.15	0.0003	0.00003	0.00004
0	2.45	0.0054	0.00053	0.00059
1	11.9	0.0262	0.00202	0.00215
2	53.5	0.1177	0.00883	0.00792
3	103	0.2266	0.01648	0.01524
4	214*	0.4708	0.03339	0.03167
TOTALS:	385 gms	0.8470 lbs	£0.06128	£0.05761

* Each fish in Trouw experiment slaughtered at a weight of 284 gms.

weights (Table 26). The observed increase in feed cost/ton liveweight gain with increasing unit weight despite the decrease in unit cost of pellets consumed is probably due entirely to the concurrent reduction in conversion efficiency. The Trouw data indicates an exponential decline in cumulative feed conversion rate to a value of 1.3 at a unit weight of 0.5 lbs., at which weight the feed cost/ton liveweight gain = £210 (Table 26). Thus the average feed cost must be 210/1.3 = £162/ton for Trouw (the average feed cost for Coopers' diet may be calculated similarly and is £152/ton, if it is assumed that Coopers' and Trouw diets have the same growth and conversion characteristics for trout).

Any change in conversion efficiency will tend to alter feeding costs, and the sensitivity of feed costs per unit liveweight gain to changes in conversion efficiency for Trouw at £162/ton and for Coopers' at £152/ton may be calculated (Table 27).

The Trouw graph of conversion rate/time was corrected for zero mortality (i.e. any dead fish counted and their weights included in the calculation). Low level mortality is expected under commercial conditions and conversion rates attained under these conditions are not usually corrected for mortality (see under 'Losses'). The usual range of conversion rates to portion size at trout farms using these two diets in the U.K. and in continental Europe is 1.4 - 1.8, assuming normal husbandry methods of intensive culture, healthy stock without 'above average' losses. Thus the feed cost incurred by rearing one ton of trout to a unit weight of 0.5 lbs. may be expected to lie within the range £213 - £292 depending upon feed type and

TABLE 26

Feed costs/ton liveweight gain of fish to different unit weights, reared on Trouw diet, predicted from results of Trouw feed experiment

Cumulative weight/fish (lbs)	Cumulative Feed Cost per unit fish on Trouw (£)	No. of fish/ton	Feed cost/ton liveweight gain (£)
0.0011	0.0003	2,036,364	61
0.0084	0.00056	266,667	149
0.0330	0.00258	67,879	175
0.1322	0.01141	16,944	193
0.2974	0.02789	7,532	210
0.5000	0.04645	4,520	210
0.9912	0.09478	2,260	214

TABLE 27

Sensitivity of Feed Costs/Unit liveweight gain for two diets to variations in Conversion Rate

Food Conversion Rate	Average feed cost/ton on Trouw (£) (fish @ ¼lb.)	Average feed cost/ton on Coopers (£) (fish @ ¼lb.)
1.0	162	152
1.1	178	167
1.2	194	182
1.3	211	198
1.4	227	213
1.5	243	228
1.6	259	243
1.7	275	258
1.8	292	274
1.9	308	289
2.0	324	304.

conversion rate. An average standard cost/ton liveweight gain under farming conditions at the present time, is considered to be £260 (i.e. FCR = ca. 1.6).

Of interest is the profile of food consumption, and hence food cost, over the life of an immature individual fish (i.e. before the onset of active gametogenesis). The data in Table 28 relates to one trout reared at 14°C on Trouvit up to 1100 gm. unit weight (ca. 2.4 lbs.). The feed cost incurred per fish reared to ca. ½ lb. weight is calculated to be £0.04678 (i.e. one ton @ ½lb. would cost (4480 x 0.04678) = £210 as calculated previously). Graphs constructed using both previous and current prices for Trouw diet and plotting cumulative feed cost against time indicate an exponential increase in the former with increasing age (Fig. 38). The relationship between cumulative feed cost and cumulative liveweight gain is, however, linear (Fig. 39).

8.3

Trash Fish (Wet) Diets

The feeding to trout of trash fish (whole or minced) has already been referred to, and is the predominant method of feeding cultured Salmonids in certain countries, notably Norway and Denmark. This type of diet has been used occasionally in the U.K. and is currently arousing interest. The economics of trash fish feeding will therefore be examined in terms of Scandinavian experience and an attempt will be made to derive implications for Scotland.

8.3.1

Economics of trash fish feeding in Norway

Trash fish feeding is employed wholly or in part on nearly all Norwegian trout farms. The fish is either caught by the

TABLE 28

Cumulative feed cost incurred by Rainbow Trout reared on Trouw diet (predicted from Trouw data)

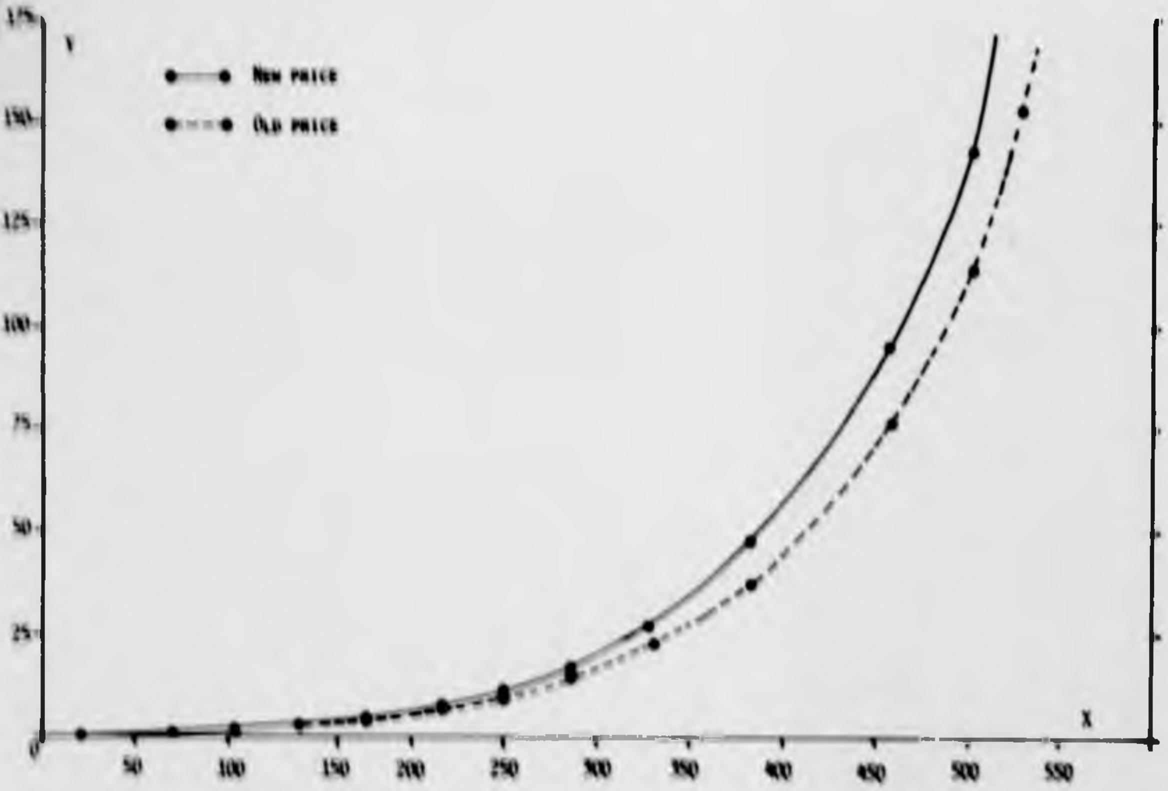
Day No.	Cum. Liveweight (lbs)	Incremental Feed Consumption (lbs)	Feed cost ($£ \times 10^{-3}$)	Cum. Feed Cost ($£ \times 10^{-3}$)
21	0.0011	0.0003	0.03	0.03
70	0.0057	0.0032	0.31	0.35
105	0.0110	0.0053	0.46	0.81
140	0.0242	0.0132	1.02	1.83
175	0.0441	0.0221	1.68	3.50
215	0.0881	0.0529	3.96	7.46
249	0.1322	0.0529	3.96	11.42
287	0.1983	0.0881	6.40	17.82
329	0.2974	0.1388	10.08	27.90
382	0.4956	0.2666	18.88	46.78
459	0.9912	0.6939	49.14	95.92
501	1.4868	0.7115	48.45	144.37
529	1.9824	0.7269	49.50	193.87
546	2.4229	0.6608	45.00	238.87

FIGURE 38

The relationships between cumulative cost of feed per fish reared and the age of rainbow trout for two different feed prices. The data is derived from Table 28 based upon the results of an experiment by Trouw & Co. using Trouvit at a constant water temperature of 14°C.

Y = Cumulative feed cost per fish (£ x 10^{-3})
X = Age from swim-up (days)
The two curves were fitted by eye.

The new price data refers to current retail prices for Trouw diets, delivered Scotland. The old price data refers to equivalent Trouw prices charged 12 months previously.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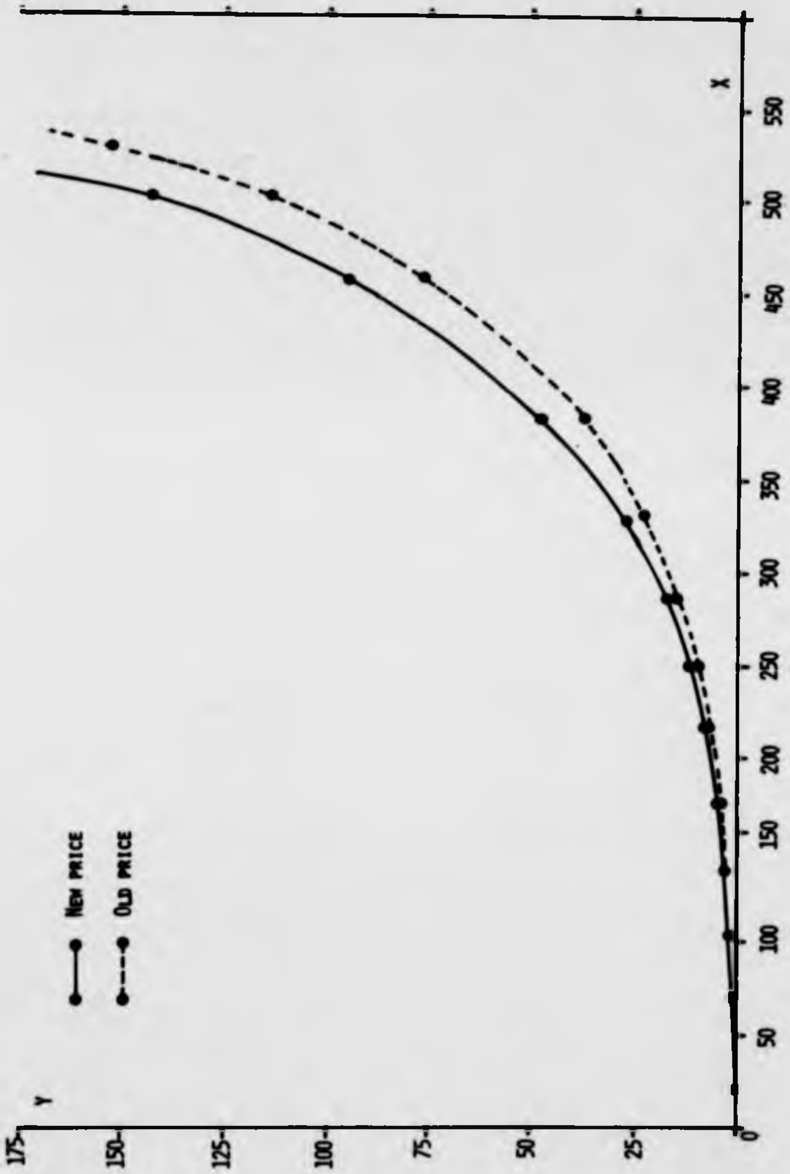
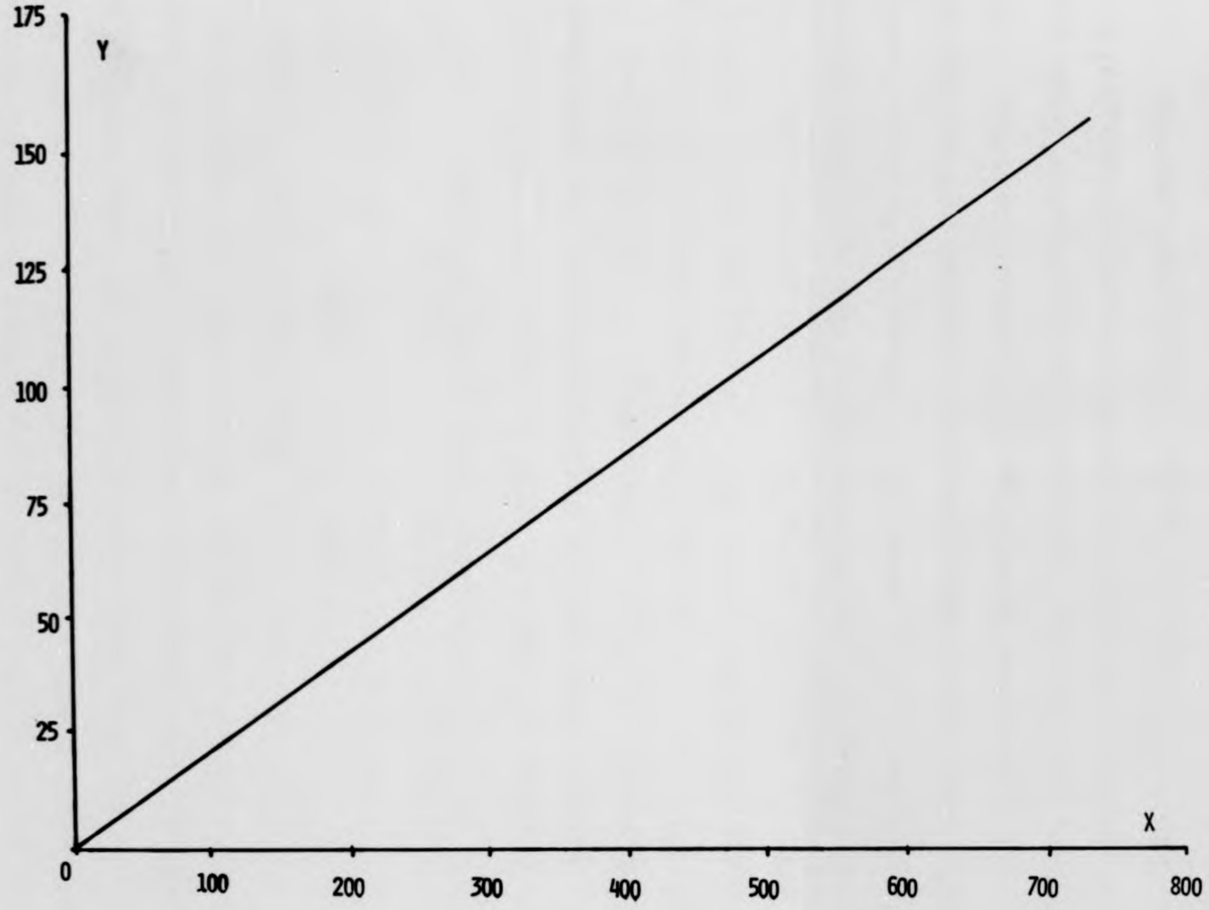


FIGURE 39

The relationship between cumulative feed cost and cumulative liveweight gain for rainbow trout. The data is derived from Table 28 based upon the results of an experiment by Trouw & Co., using Trouvit at a constant water temperature of 14°C.

Y = Cumulative feed cost per fish (£ x 10^{-3})
X = Cumulative liveweight gain per fish (g.)
$Y = 0.22\ X$

Information was not available on the nature of the scatter of individual plots in this experiment; thus it is assumed that $r = 1.0$.


175
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farmer or purchased as (usually) unprocessed frozen blocks before being minced and fed. The farmed fish are generally grown to ca. 1 kg. (2.2 lbs) in unit weight and fed shrimp in order to pigment the flesh. Table 29 summarizes data on the cost/effectiveness of Norwegian trout diets, derived from Berge (1968) and the Norwegian School of Business Administration (1971). The mean food conversion rates for dry feed (for fry and fingerlings), Herring, Coalfish and Shrimp were 1.95, 6.25, 6.70 and 5.75 respectively. The mean feed costs per ton liveweight gain for Dry Feed, Herring and Coalfish were £185, £112 and £138 respectively (£194, £105 and £138 if only the 1969 sample is considered). The variation in Shrimp costs is large and its nutrient value is secondary to its pigmentation factor for the farmer. This range of costs for trash fish was confirmed for Atlantic Salmon culture also (Devik, personal communication); wet diets at Mowi A/S, Bergen were as follows:

Diet	Cost of feed* (£/ton)	Food Conversion Rate	Feed cost/ton liveweight gain (£)
Small Herring	26	4.75	124
Coalfish	20	6.4	128

* (@ Exchange Rate (April 1971) of 18 kr. = £1.00)

Comparisons between wet and dry pellet feeding should also consider (i) possible incremental operating costs (discussed hereafter) for wet diets and (ii) the fact that in Norway dry feeding is practised only with small fish whose conversion efficiency is higher than that of Norwegian trout at slaughter (i.e. if the effect of dry feeding between fish @ 0.5 lbs. and 2.2 lbs. is compared, there is likely to be a difference of ca. 8% in conversion efficiency in favour of the former unit

TABLE 29

Summary of cost/effectiveness of Norwegian wet fish feeding in trout culture

Sources: (i) Berge, L. (1968)

(ii) Norwegian School of Business Administration (1971)

N.B. Costs are given to the nearest £ (Sterling) after conversion from Norwegian kroner using the appropriate exchange rates.

A. DRY FEED

Year	Food Conversion Rate	Food Price (£)	Food Cost (£)/ ton liveweight gain
1969	2.0	95	190
1969	2.0	89	178
1969	2.0	95	190
1969	2.0	89	178
1969	2.0	107	214
1969	1.9	113	215
1965	1.7	92	156
1965	2.0	79	158

B. HERRING

Year	Food Conversion Rate	Food Price (£)	Food Cost (£)/ ton liveweight gain
1969	7.0	12	84
1969 (heads)	5.5	20	110
1969 (small herring)	5.0	24	120
1965	4.5	15	69
1965	6.5	23	149
1965	8.5	19	160
1965	5.0	17	83
1965	8.0	15	122

C. COALFISH

Year	Food Conversion Rate	Food Price (£)	Food Cost (£)/ ton liveweight gain
1969 (young coalfish)	7.0	24	168
1969 " "	6.0	18	108
1969 (adult coalfish)	7.0	20	140
1969 (young coalfish)	7.5	18	135
1969 " "	5.5	24	142
1969 (adult coalfish)	7.0	24	168
1969 (young coalfish)	7.0	15	105

Table 29 (continued)

D. SHRIMP

Year	Food Conversion Rate	Food Price (£)	Food Cost (£)/ ton liveweight gain
1969	7.0	36	252
1969	7.0	36	252
1965 (shrimp waste)	7.0	26	178
1965	4.0	5	20
1965	6.5	15	99
1965 (shrimp waste)	3.0	26	77

weight; this difference, which is correspondingly reflected in the cost of unit liveweight gain, will be increased with comparisons between fish @ 2.2 lbs. and fish @ 0.5 lbs. unit weight).

8.3.2.

Economics of trash-fish feeding in Denmark

In Denmark, where trout are reared to ≯ 10 ozs. unit weight and trash-fish feeding is almost universally employed for trout, other than fry, food conversion rates vary from 4.5 - 8, depending on quality of the diet, use of binder, standard of husbandry, etc. The price of trash fish (c.f. Norwegian; incl. Sand Eels, excl. Shrimp) which is delivered to the farms, varies considerably from one year to another and also exhibits seasonal fluctuations. For the decade preceding September 1971, maximum and minimum prices for trash fish (excl. transport) were £26/ton and £15/ton respectively (Dessau-Arp, personal communication.). During 1972, as the international fishmeal market began to harden, price levels were higher throughout the year and the (characteristic) seasonal price extremes in March and September were £28/ton and £20/ton respectively (Jensen, personal communication); in March 1973, prices were at a record high of ca. £31/ton (Jørgensen, personal communication).

	£/ton
In the latter case, assuming: Feed Cost =	31
Binder cost (included @ 4% of feed) =	5
Feed transport cost =	3
	39

If Food Conversion rate = 5.0, then food cost/ton liveweight gain = £195.

It is claimed that incorporation in the diet of an alginate or methylcellulose binder (Skretting A/S, Stavanger, Norway) enhances food conversion rates by 0.5 when fed at 4% of total feed (Jensen, personal communication). At this level, the binder cost £5.1 per ton of feed in April 1972 and the alternatives would be: (i) without binder (e.g. Feed @ £31/ton) Feed cost/ton liveweight gain = £31 x 5.5 (FCR) = £170.5 (ii) with binder, and consequent claimed reduction in FCR Feed cost/ton liveweight gain = (£31 + £5.1) x 5 = £180.5. Thus addition of a binder would appear to be uneconomical on this basis. It could be that a greater increment than 0.5 in conversion efficiency accrues at the 4% rate. Also, legal and husbandry constraints might appear in the absence of a binder (e.g. due to pollution problems preventing as high stocking rates in the ponds and causing a social nuisance at the outfall).

The cost of feed transport is dependent upon the distance of the farm from the nearest port. In Denmark, communications are simple and distances to ports relatively small; £3/ton is an average transport cost for an inland farm. Transport costs/ton liveweight gain for wet diets are ca. 4 times those of dry diets because of the higher moisture content, and hence mass.

In attempting to compare the economics of dry and wet diets, it is important to consider the fluctuations in the prices of each over time as well as the variations in conversion efficiency (e.g. due to disease outbreaks) which may occur even at one farm, e.g. Forsøgsdambruget Brons (Table 30). In this example, it may be observed that in only one year (1966), of the five under consideration, was the dry feed relatively more attractive than the wet, and this coincided with a high price and poor conversion efficiency for the wet food. However, this analysis ignores certain incremental operating costs associated with trash-fish feeding, notably the cost of plant and machinery

TABLE 30

Cost/effectiveness of dry and wet diets on a Danish farm (1964-1968)

Source: Bregnballe (Personal communication)

Year	Diet	Average Feed Cost (Incl. transport) (£/ton)	Average Food Conversion Rate	Food Cost per ton liveweight gain (£)	Cost of feed as percentage of unit production cost
1964	Dry	77	1.6	123	52
	Wet	18	6.6	119	
1965	Dry	95	1.6	152	54
	Wet	21	5.2	109	
1966	Dry	80	1.6	128	55
	Wet	21	7.3	153	
1967	Dry	94	1.6	150	49
	Wet	19	6.05	115	
1968	Dry	116	1.6	187	48
	Wet	17	6.86	117	

N.B. On this farm, fish were reared entirely on dry diets until ca. 7 cm. in length and thereafter exclusively on wet diets. Since conversion efficiency naturally declines with age, a meaningful comparison of dry and wet diets is not possible in this case.

for mincing (including power costs),-possibly increased labour costs and (on certain farms, especially in Norway) freezing and cold store costs.

The average cost of dry feed in Denmark during 1972 was £110 (Clarks' Ørredfoder). At that time, in comparing the wet and dry diets available in Denmark, it was stated by one authority (Nielsen, personal communication) that it was possible to produce 1 ton of trout at a cost for wet feed of £141, but impossible to produce an equivalent weight with dry feed at less than £170 (assuming an exchange rate of 18 kr./£) including all costs. If it is assumed that any subsequent price escalations of wet and dry diets have been equivalent, then it may be concluded, other things being equal, that wet diets permit the possibility of certain economies compared with dry diets in Denmark. Nevertheless under conditions of relatively high trash-fish prices, poor conversion efficiencies and/or high incremental operating costs with wet diets, this situation may be reversed.

8.3.3 Trash-fish feeding: implications for Scotland

(i) U.K. experience

One English trout farm (Wansford) fed Herrings and Sprats @ £20/ton delivered and claimed conversion rates of ca. 4.0; this practice was eventually prohibited by the local river authority because of alleged pollution (Damm, personal communication). Sedgwick (1970b) attempted to summarize the feed costs at Howietoun and Northern Fisheries, Loch Strom, which used wet fish offals from a Lerwick processing plant, as in Table 34.

TABLE 31

Feed Costs at Howietoun (Shetland): after Sedgwick (1970)

Feed	Cost of Feed (£/ton)	Food Conversion Rate	Cost/ton liveweight gain (£)
Wet	6	7	42
Dry	110	1.5(Large Trout) 2.0(Small Trout)	165 - 220

However, this analysis is unrepresentative since after three months' operations, the cost of wet feed escalated to £20/ton (Shorthouse, personal communication). Moreover, Sedgwick's estimates of conversion efficiencies on dry feed for 'large' and 'small' trout appear to be mistakenly juxtaposed.

A recent cost-effectiveness study compared the costs to one (west coast) Scottish location of three diets as feeds for marine flatfish. It is probable that conversion efficiencies obtained for Trout would not be dissimilar to those recorded for Plaice in this experiment, if reared under similar conditions (Table 32).

TABLE 32

Cost/effectiveness of three diets for farmed Plaice

Diet	Delivered Cost (£/ton)	Food Conversion Rate	Feed cost/ton liveweight gain (£)
Queen offals	95	6.5	617.5
Reclaimed Cod flesh	140	3.7 - 4.1	518 - 574
Trout pellets	157	1.2 - 1.9	188 - 298

This evaluation incorporates all delivery and processing costs and clearly demonstrates the superiority of the pellets over the two alternative diets.

(ii) Future implications

Experience with wet fish diets in Scandinavia and the U.K. would indicate that certain factors are likely to be of significance in considering its further development in Scotland:

i) the probability that it would be prohibited at fresh water sites on grounds of pollution

ii) the absence of an industrial fishing fleet to provide a regular supply of trash fish

iii) problems of poor communication, especially in the West of Scotland.

The possibilities for a trout farmer at a marine location in Scotland wishing to feed trash fish might then be:-

i) Siting of the farm in close proximity to a port or fish-processing factory

ii) provision of cold-store facilities at the farm

iii) the farm fishing, or contracting to fish for, its own supply of trash fish.

Consideration of the third alternative is strengthened by the existence of hitherto unexploited stocks of certain 'trash' species (e.g. Blue Whiting (*Gadus poutassou*)) in areas around the North-western Scottish seaboard. For the annual production of 1,000 tons of trout, *ca*. 6,000 tons of trash fish might be required. Johnston (personal communication) estimated that this annual landing would require 8 x 55' fishing boats, each of which might bear a second-hand purchase cost of *ca*. £22,500 plus £18,000 for gear and annual operating costs as follows:

Wages and Fuel	£7,500
Depreciation on boat	£2,250
Depreciation on net	£5,000
	ca. £16,000

The cost/ton liveweight gain on this basis would be $\frac{(8 \times 16,000)}{1000}$ = £128, excluding extra and incremental operating costs, notably mincing and cold store.

8.4 Summary

An analysis is made of the biological and economic problems involved in trout feeding with special reference to dry pellets and wet fish diets. The price of dry pellets is rising but is expected to stabilize; at a conversion rate of 1.6, the cost/ton liveweight gain is currently ca. £260 for Trouw and Coopers' diets. By comparison, at a conversion rate of 6, the cost/ton liveweight gain for wet feed might be ca. £180 if bought-in but might fall to ca. £128 if fished by the farm itself (these costs excluding mincing, freezing and incremental labour costs). Wet fish feeding involves higher operating costs than dry feeding and the possibility of pollution increases the attractiveness of a marine rather than fresh water site. Dry pellets have certain fringe benefits, notably suitability for automation and ease of storage without cold store facilities. It could be that dry feed is inferior to wet feed with respect to growth rate and conversion efficiency (on a comparable base, e.g. dry matter) under certain circumstances.

CHAPTER 9

CAPITAL COSTS

9.1. Introduction

Kingsbury (1951) referred to 'a great divergence of opinion as to the cost of producing trout'; he suggested that the greatest cause for such divergence was the lack of a standard method of keeping hatchery records which would ensure uniform production statistics and permit direct comparison of costs. Although this statement is still valid at the present time, it may be argued that disparities in capital cost represent the largest problem involved in making comparisons of cost data for trout culture.

Numerous factors influence the capital cost of a trout farm, among which are:

i) the husbandry systems used

ii) the natural characteristics of the site

iii) the cycle of operations performed and scale of production

iv) the constraints on finance, labour, etc. of the investing organization.

It does not necessarily follow that a highly capital intensive farm will incur larger annual costs of production than a farm of low initial investment; the former may have a longer economic life, permit economies in certain operating costs (e.g. maintenance, labour) and be associated with a more favourable risk factor.

9.2 Methodology

Capital costs will be considered under the three categories of (i) Hatchery, (ii) Early rearing, (iii) On-growing, of which either one or two categories may be wholly or partially omitted with specialization under farm conditions. A major problem arose in attempting to arrive at real or notional costs for current investments in trout culture in the U.K. Much cost data obtained was historical and in some cases related to foreign investments and was in the currency in which it was incurred. Since it was desired to bring all cost data (at least relating to capital costs) to a common base so as to allow a trout farmer to make meaningful estimates and comparisons for 1973 in Scotland, Sterling was employed as a common currency. The exchange rates used were mid-point rates at the end of the year. While it is not necessarily the case that an investment in one country outside the U.K., when converted to Sterling using the appropriate exchange rate, gives the value of an identical investment in the U.K. at the same time, it was decided to make this simplifying assumption.

It was desired to make an attempt at updating historical costs to the present in order to provide a cost basis for assisting current investment decisions. This was performed using the index numbers for wages and wholesale prices in the U.K. construction industry (Table 33). Where the cost elements for labour and materials could not be differentiated, the mean of the two sets of indices was used. The conversion factors used are thus only approximate. However, they are used primarily in order to permit comparisons to be made (e.g. international comparisons of costs and viability being relevant, since the product is traded on the open market). For comparative purposes, the errors attributable to inaccurate conversion factors are less important.

Table 33 Cost indices used for converting historical data to 1973

I Year	II Wage Index	III Construction Index	IV Mean Index	V Mean Conversion Factors
1964	100	100	100	1.89
1965	104	105	104.5	1.81
1966	110	110	110	1.72
1967	117	112	114.5	1.61
1968	128	117	122.5	1.54
1969	132	122	127	1.49
1970	151	130	140.5	1.35
1971	172	140	156	1.21
1972			172	1.10
1973 (March)			189	1.00

Column II is derived from the index numbers of basic weekly rates of all manual workers in the U.K. Construction industry and Column III from the index numbers of wholesale prices in new construction in U.K.; data expressed for 1965 datum and corrected for 1964 (Source: Monthly digest of Statistics, H.M.S.O. Jan., 1972).
Column IV = (Column II_t + Column III_t)/2. Column V_t = 189/ Column IV_t. Mean indices for 1972 and 1973 are each 110% of previous year's mean index (Woodward, personal communication).

All costs referred to hereafter are converted to Sterling, where necessary, and are inflated to present day costs, unless otherwise stated.

9.3 Hatchery

If a hatchery is used merely to accommodate incubation systems up to the stage at which alevins are coming on to feed, then the total capital cost is usually small.

Investment is usually required for egg trays, piping and some form of shelter. A standard Aluminium egg tray (Grice and Young Ltd.) for 50,000 eggs bears a retail price of £18.50 and may be inserted in an early-rearing trough costing

£25, the whole system being capable of rearing to fry stage (i.e. potential production of ca. 10 tons of portion fish). Piping connections at one unit producing 200,000 fingerlings per annum cost £128 (Fessler and Scott, 1969). The provision of shelter is likely to incur capital costs in excess of the sum of the fittings contained inside.

The use of embryonator systems would permit economies in the cost of the incubation facility and in the volume of space required. However, such systems function more efficiently when the water is filtered at additional cost; also the alevins require an alternative facility to the embryonator.

9.4 Early Rearing

It is no longer common practice to place fry in the same form of facility as used for on-growing of trout. Early rearing usually employ one or two different facilities, and there is not generally a requirement for housing if some protection against predators (e.g. nets) is provided. Ranges of cost for this stage under different conditions may be illustrated by Table 34 and by five examples:

(i) unit producing 10 tons portion trout p.a. (Howietoun and Northern Fisheries Co. Ltd., 1972).

	£
six 6' x 6' x 2' fibreglass tanks	330
six demand feeders (small)	48
piping, valves, etc.	100
	£478

(ii) unit producing 200,000 fingerlings p.a. - equivalent to 45 tons of portion trout p.a. (Fessler and Scott, 1969).

	£
Shelter (16' x 12' - Aluminium roof)	64
three concrete tanks (16' x 3' x 2.5')	193
three hatching troughs	193
Piping	64
gross	£514

TABLE 34

Commercially available Fibreglass Early-rearing tanks in U.K.

Manufacturing Company	Dimensions	Volume (ft^3)	Advertised carrying capacity (lb/ft^3)	Retail Price (£)
Grice & Young Ltd.	2.5' x 2.5' x 10"	5.2	-	16
Grice & Young Ltd.	6' x 6' x 2'	72	4.9	67
Plade Ltd.	6' x 6' x1.5'	54	3.7	55

(iii)unit producing 80 tons portion trout p.a. (Kenmure Fisheries Co. Ltd. - personal communication)

	£
twenty 20' x 2½' x 2½' concrete formed fry tanks (incl. building)	2,400
Twenty D.O.F. automatic feeders with time switch etc.	280
Piping, valves, etc.	120
Excavating and levelling site	150
	£2,950

(iv) unit producing 100 tons portion trout p.a. (Macfarlane, personal communication).

	£
Burrows filter, concrete round tanks	1,500
eighteen 10' x 10' x 2' fry ponds (fibreglass) including all piping and valves, filters, excavation, etc.	5,280
	£6.780

(v) unit producing 534 tons of portion trout p.a. (Macfarlane, personal communication).

	£
Filters (incl. excavation, building and gravel)	1,697
40 ponds @ 6' diam. (fibreglass)	1,880
40 ponds @ 12' diam. (fibreglass)	10.000
	£13.577

The capital costs incurred by early-rearing comprised 15%, 9%, 8%, and 8% of the total capital costs of the farms in examples (i), (iii), (iv) and (v). These various early-rearing systems are designed to bring fish through from first feeding to a unit length of *ca*. 3" (6 - 8 cm.). Factors which have a significant influence on capital cost include:-

(a) whether early rearing is a single or two-stage process. The latter, as in examples (iv) and (v), usually incurs heavier capital costs but is often associated with operating economies (reduced losses, economies in water, feeding, etc.).

(b) ability to obtain first feeding fry throughout the year. A comparison of the second stages of early rearing of examples (iv) and (v) demonstrates considerable economy in rearing volume requirements with the larger unit (v), i.e. 6,800 ft^3 (534 tons p.a.) against 3,600 ft^3 (100 tons p.a.). This is achieved by buying-in eggs throughout the year and obtaining an approximate steady state with a consequent reduction in number of early rearing facilities.

(c) provision of shelter. Unless obtained as e.g. war surplus (example (iii)), this may cost ca. £4/ft^2 for an area in excess of 1,000 ft^2. Many Danish farms cover only the feed store.

9.5 On-Growing

Capital outlays for on-growing may be classed under six categories: (i) Land, (ii) Excavation, (iii) Holding facilities, (iv) Dams, Pipelines and valves, etc., (v) Buildings and (vi) Plant and Machinery etc. (pumps, processing equipment, miscellaneous).

9.5.1 Land

There is great diversity in land prices which generally reflects the usefulness of the site for construction. In site purchase for fish farming, however, the water supply is usually the most critical factor and may similarly influence the price. A 3 acre site in Dorset with a guaranteed 600 g.p.m. supply of bore-hole water (formerly a water-cress farm) is currently for sale at an advertised price of £28,000. On the Scottish west coast, good arable land is available in one location at ca. £400/acre (Kenneth, personal communication), while two sites under consideration for trout farming were available at £150/acre (Macfarlane, personal communication). Using the latter figure, it is evident that land purchase is likely to be a small part of total cost (Table 35), unless the price is elevated because of the water supply.

9.5.2 Excavation

During site evaluation, a survey of the ground conditions is undertaken whose results are used to assist the choice of husbandry system to be adopted. Thus excavated earth pond systems are usually only considered where the terrain may easily be excavated. The presence of rock can cause considerable cost escalation for excavation which may increase the attractiveness of alternative systems requiring minimal excavation, e.g. round tanks, raceways. Excavation is usually also required for provision of hatchery, store, pumphouse and piping as required. The largest cost for excavation recorded at a commercial trout farm in operation was 10% of the total capital cost (Shorthouse, personal communication). Contracted excavation charges currently average _ca_. 50p./yd^3 (Macfarlane, personal communication). The volume of an earth pond = _ca_. 555 yd^3 and the volume/pond of inlet and outlet channels = _ca_. 122 yd^3, which would entail a total excavation cost of _ca_. £339/earth pond, if no rock, although these charges would be greater for small quantities.

9.5.3 Holding Facilities

(i) Excavated earth ponds and raceways

These are of variable dimensions and generally the raceways will be depreciated over a shorter period than earth ponds because of the higher flow rates and erosion problems. For

TABLE 35

Land requirements for three Trout farming systems and consequent costs of land

System	Surface area per unit (incl. necessary surrounds) (ft^2)	Average production capacity per unit @ Production ratio = 1:1.6 (tons p.a.)	Potential production of trout per acre (tons p.a.)	Cost of land (@ £150/acre) for annual production of 100 tons of trout (£)
Earth ponds	5,000	3.6	31	480
Raceways in parallel (unit = 2 raceways)	2,500	4.8	83	180
15' diam. tanks	400	1.6	167	90

the same reason, fittings (control sections, etc.) usually bear a larger capital cost for raceways than for earth ponds. The cost of excavation (Table 36) assumes that a contractor is employed and that no rock is encountered. However, if the farmer excavates his own ponds or raceways, reduction or omission of labour costs at opportunity cost rates will often permit apparently lower excavation and total pond costs. These costs may be compared to American costs reported by Fessler and Scott (1969) as follows:

Initial investment costs per raceway:-

	£
Earth raceway (100' x 30' x 3')	161
Concrete control sections	161
Screen (½" x ½")	10
One set of dropboards	5
	£337

(ii) Fabricated Raceways

These are constructed currently in concrete, fibreglass cement or brick, and are typically of dimensions: 100' x 8' x <u>ca.</u> 3' (depth of water is usually <u>ca</u>. 1.5', giving a usable volume of 1,200 ft^3). Durability of construction permits fast flow rates and high stocking densities (e.g. 2.8 $lb./ft^3$) and a long economic life; the fabric may be depreciated over a period of 20 years, although for financial reasons an assumption of 10 years might be preferred. Unit costs for various fabricated raceways in Table 37 are derived from Gateway West Argyll Ltd., Highland Trout Co. Ltd. and I. S. Macfarlane (personal communication) and make the following assumptions:

(i) Brick and concrete raceways are constructed in parallel and share a common centre wall.

TABLE 36

Unit costs of excavated systems for trout farming

System	Excavation per unit cost @ 50p./yd^3 (£)	Approx. capital cost per unit of fittings (damboards, control sections) (£)	Depreciation period (yrs)	Production capacity/unit per annum assuming Production ratio = 1:1.6 (tons)	Cost for Depreciation per ton per annum (£)
Earth pond + channels 100' x 30' x 5'	339	10	10	3.6	9.4
Scottish earth raceway * 100' x 8' x 1.5'	30	40	5	0.9	15.6
Wide American raceway ** 100' x 30' x 3'	167	150	5	6.4	9.9

---

* Cantray Trout Farms Ltd. with stocking density @ $\frac{1}{2}$lb. - 1lb./ft^3.

** (i) assuming stocking density @ $\frac{1}{2}$lb. - 1lb./ft^3
(ii) 10 years life is sometimes assumed in America - in which case the cost for depreciation/ton p.a. would be £5.0/ton.

TABLE 37 Unit costs of fabricated raceway systems

System	Capital cost/raceway (£)	Production capacity/unit p.a., assuming Production Ratio = 1:1.6 (tons)	Depreciation period (years)	Cost for depreciation per ton p.a. (£)
Brick	648	2.4	10 (20)	27 (14)
Fibreglass cement	700	2.4	10 (20)	29 (15)
Concrete	933	2.4	10 (20)	39 (19)

(ii) Concrete bases cost *ca*. £3/yd^2

(iii)Brick walls cost *ca*. £7/yd^2

(iv) Moulded raceways in fibreglass cement of these dimensions cost *ca*. £7/running foot.

(v) Concrete raceways of these dimensions cost £725–£933 per raceway (the latter includes all concrete work, inflow pipes, drainage, filters, shuttering, etc.).

Mayo (1971) indicated the existence of economies of scale for capital cost in relation to rearing volume of raceways and holding ponds in the U.S.A. This might be expected for a fabricated system from theoretical considerations. In this case, if no excavation is required and the cost of land is ignored, it is likely that capital cost will be related to the surface area of materials used in construction. Since capital cost and rearing volume are thus likely to be proportional to the square and cube respectively of the linear dimensions of the system, it follows that capital cost is likely to be proportional to rearing volume raised to a ⅔ power.

Cost/volume relationships are likely to be different for excavated systems. In this case, cost is likely to be related to the volume, or mass, of earth removed, i.e. both capital cost and rearing volume are likely to be proportional to the cube of the linear dimensions of the system. Thus one might expect a linear relationship between capital cost and rearing volume for excavated systems and this is supported by data from a sample of seven earth pond systems which indicate an approximately *pro rata* increase in capital cost with increased annual production capacity (Fig. 40).

(iii) Lining materials

The use of certain synthetic materials is being explored

FIGURE 40

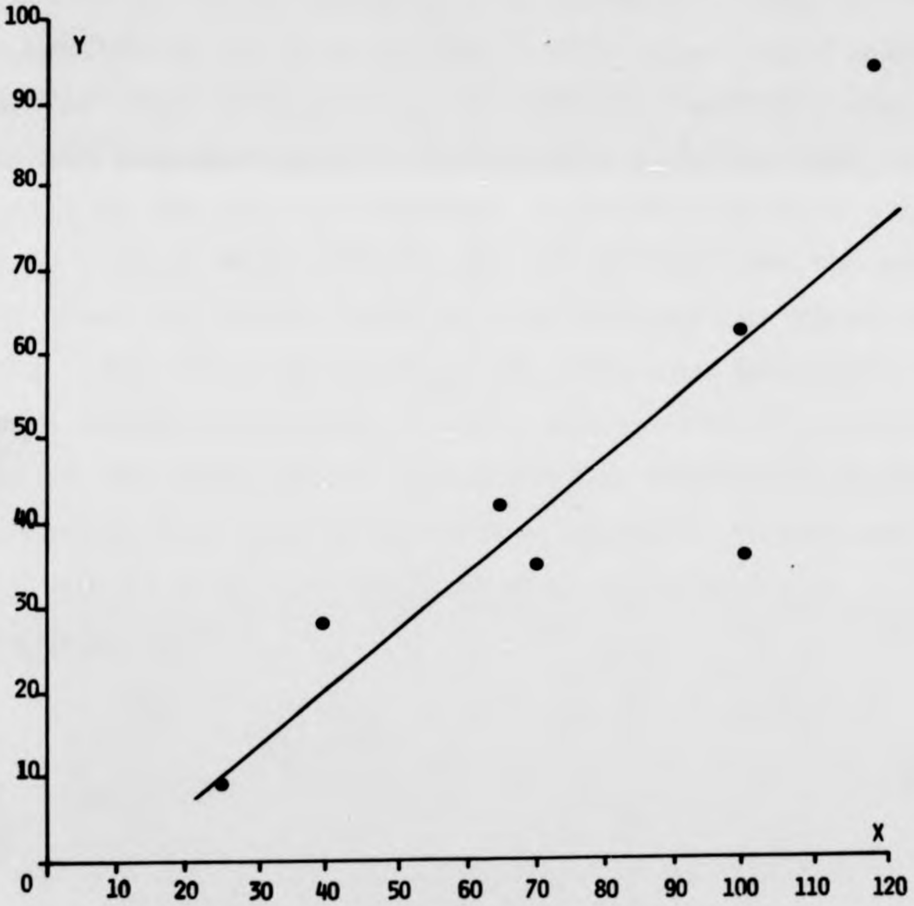
Relationship between total capital cost and maximum annual production for a sample of seven trout farms in the U.K., Ireland and Denmark, which use only excavated earth ponds.

Y = Total capital cost (£ x 10^3)

X = Maximum annual production (tons)

Y = 0.69 X - 7.19

r = 0.87 $p < 0.01$ 1%



Y
X
0
10
20
30
40
50
60
70
80
90
100
110
120

e.g. for lining earth ponds in order

(i) to reduce erosion

(ii) to ease disinfection,

(iii)to permit trout farming in porous soils. Relevant costs are given in Table 38.

(iv) Circular tanks

Circular tanks are becoming increasingly common for trout culture because of certain operating advantages (e.g. self-cleaning) and are fabricated in fibreglass, concrete, etc. Robinson and Vernesoni (1969) described a circular tank constructed by the use of preformed concrete silo staves in the U.S.A. These are now available in the U.K. and the unit costs of these and other circular tank systems are given in Table 39. The same sample (Fig. 41) indicates that economies occur with increased rearing volume, and the relationship is possibly of the order postulated above for fabricated systems. It is probable that some of the other operating advantages of circular tanks are reduced or lost with ponds of large diameter (e.g. 730').

TABLE 38

Unit costs of three synthetic linings for earth ponds (e.g. dimensions = 100' x 30' x 5')

Material & Gauge	Retail price/yd^2 (pence)	Price/4,300 ft^2 i.e. per pond (£)	Total cost/pond incl. excavation etc. (£)	Cost for depreciation (10 years) per ton p.a., assuming production capacity per pond = 3.6 tons p.a.
Polythene 500	2.8	14	302	8.4
Polythene 1000	5.6	27	315	8.8
Famliner * ¼"	49	25	313	8.7
Famliner ½"	64	306	594	16.5
Butyl 20/1,000	72	344	632	17.6
Butyl ** 30/1,000	80	382	670	18.6

* Famliner from D. Anderson & Sons, Stretford, Manchester

** Butyl from Butyl Products Ltd., Billericay, Essex.

TABLE 39 **Characteristics and Unit Costs of Circular tanks for trout farming**

Material	**Source/Manufacturer**	Rearing volume **(ft^3)**	Production Capacity p.a. (tons) = Rearing Volume x 2 (lb/ft^3) x 1.6 (Production ratio) / 2240 (lb/ton)	Retail Price **(£)**	Assumed Depreciation **period (yrs)**	Cost of Depreciation per ton p.a. **(£)**
Fibreglass cement	I.S.Macfarlane	50	0.071	68	10	95.8
" "	"	50	0.071	68	20	47.9
" "	"	250	0.357	145	10	40.6
" "	"	250	0.357	145	20	20.3
Fibreglass	Grice and Young	339	0.485	250	10	51.6
"	" " "	339	0.485	250	20	25.8
"	" " "	339	1.065 ø	250	10	23.5
"	" " "	339	1.065 ø	250	20	11.7
Concrete	Robinson & Vernesoni	471	0.674	310	10	46.0
"	" "	471	0.674	310	20	23.0
Fibreglass	Grice and Young	707	1.010	355	10	35.2
"	" " "	707	1.010	355	20	17.6
Fibreglass	" " "	707	1.616 *	355	10	22.0
"	" " "	707	1.616 *	355	20	11.0
Concrete Silo staves**	Howard Harvestore	3,181	4.544	1,182	10	26.0
" " "	" "	3,181	4.544	1,182	20	13.0
" " "	" "	7,975	11.393	1,915	10	16.8
" " "	" "	7,975	11.393	1,915	20	8.4
" " "	" "	11,284	16.120	2,359	10	14.6
" " "	" "	11,284	16.120	2,359	20	7.3

** Prices given for system installed; otherwise it is assumed that installation is performed by the farm

ø Assumes stocking density @ ½lb = 4.4 lb/ft^3 as advertised ⎫

* " " " " " = 3.2 lb/ft^3 " " ⎭ otherwise stocking density @ ½lb is assumed to be $2lb/ft^3$.

FIGURE 41

The relationships between capital cost and rearing volume for a sample of eight fibreglass circular fish tanks, commercially available in the U.K.

a) Y = Capital cost (£ x 10^2)

X = Rearing volume (ft^3 x 10^3)

$Y = 4.65\ X^{0.7}$

$r = 0.99$ $p < 0.001$

b) Y = Capital cost per unit capacity (£ x 10^{-1}/ft^3)

X = rearing volume (ft^3 x 10^3)

$Y = 0.46\ x^{-0.3}$

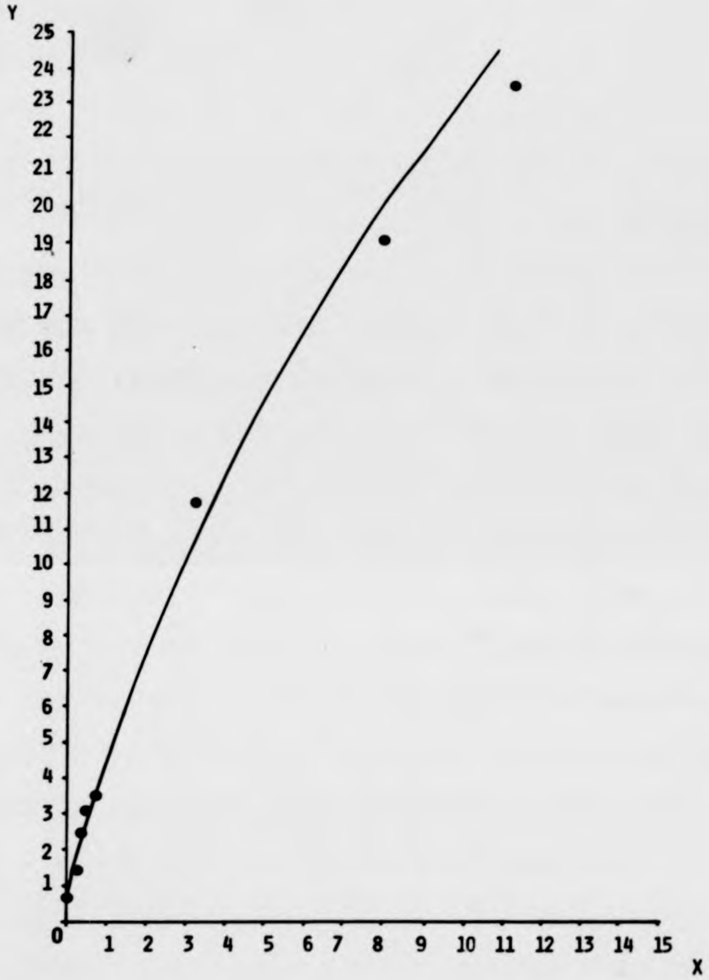
$r = 0.99$ $p < 0.001$

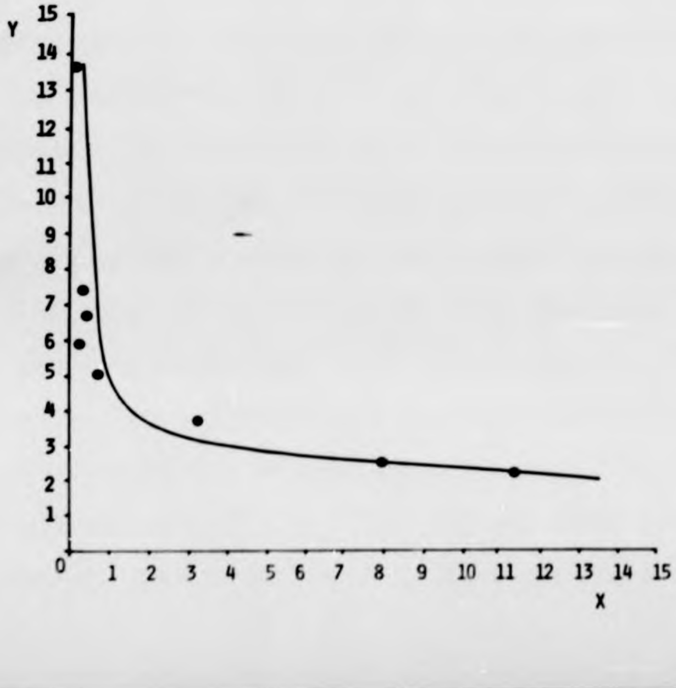
earing

ular

K.

$10^{-1}/ft^3)$





(v) Floating Facilities

Bag nets with a flotation collar are currently in use at two Scottish sites: a freshwater loch on Lewis and a sea loch in Argyll. In addition, bag nets were used on a metal frame in a fixed enclosure at a sea loch (Loch Strom, Shetland), from 1968 - 1970 and floating metal cages have been used by Unilever Bros. at Lochailort, Inverness-shire for trout culture in a sea loch, but no details are available. The cost of nets (Table 40) depends on (i) dimensions, (ii) material, (iii) mesh size.

If it is assumed that water exchange is sufficient to enable fish to be held at a stocking density of 2 lbs./ft^3, and that a maximum height of 3' of the Shetland net is exposed and thus unproductive, then the carrying capacity of these facilities may be computed and hence the production capacity, assuming a production ratio of 1 : 1.6 (Table 41).

The annual production cost is computed assuming an economic life for each net of 3 years. It excludes the cost of a flotation collar, which may be constructed in a variety of ways, e.g. wooden frame, air filled drums, fibreglass filled with polyurethane, styrofoam covered with aluminium, etc., the cost of which is usually small relative to that of the net it supports, unless additional investments are made, e.g. in predator proofing and access walks around the perimeter of the net, as at one site in Scotland (Marine Harvest, Lochailort) from which costings have not been obtained.

Studies by Berge (1968) and the Norwegian School of Business Administration (1971) have demonstrated a declining cost of 'floating ponds' per unit volume with increasing total rearing volume. These costs have been converted to Sterling

TABLE 40

Characteristics of Scottish netted systems (I)

Site	Dimensions	Cost (£)	Cost/ft^3 (p)	Material	Mesh size (if known)
Stornoway, Lewis.	20'x20'x6'	250	10.4	-	-
Kames, Argyll	12'x12'x12'	35	2.0	Woven Terylene	-
Strom, Shetland	45'x30'x10'	274	2.0	Courlene	0.4"
?	12'x12'x12'	87	5.0	Knotted Polythene	-

TABLE 41

Characteristics of Scottish netted systems (II)

Site	Carrying Capacity per net p.a. (tons)	Production Capacity per net p.a. (tons)	Cost for depreciation per ton of fish p.a. (£)
Lewis	2.14	3.43	24.30
Kames	1.54	2.47	4.72
Shetland	8.44	13.50	6.77
?	2.47	2.47	11.74

and updated in the graph (Fig. 42) which incorporates a sample of 17 farms with rearing volumes from 710 ft^3 to 37,070 ft^3. The sample is of sea water farms and flotation is provided by wood and/or polystyrene. The graph would appear to indicate that there is a rapid decline in unit cost for floating ponds whose volume is in excess of ca. 10,000 ft^3.

(vi) Other Systems

Other systems on which cost data has been obtained include various sublittoral systems notably fixed sea enclosures. The only such system which has been operated in Scotland used mesh bag nets suspended from a fixed framework of scaffolding poles in Loch Strom, Shetland (see under (v) Floating Facilities). The cost of the fixed framework and catwalk (incl. piling) = £6,908. Therefore, total cost (incl. 14 nets) = £10,746 (for total production capacity of 13.5 tons p.a. per net).

Cost p.a. of each net = £91.3 (depreciated over 3 years)

Cost p.a. of framework/net = £49.3 (depreciated over 10 years)

Hence total cost/ton production p.a./net = £10.4.

Enclosures in Norwegian trout culture generally comprise systems of nets in sea water. Data derived and modified from the Norwegian School of Business Administration (1971) is presented (Fig. 43). Graphs of capital cost against capacity show an approximately linear relationship between rearing volume and for capital cost. Such systems are very variable in design, and hence cost, since they are adapted to suit and exploit a particular cove, sound, etc.

9.5.4 Dams, Pipelines and Valves, etc.

Dams and associated inlet screens are of extremely variable design and costs. Dams may be constructed of timber, concrete,

FIGURE 42

Relationship between capital cost per unit capacity and rearing volume for a sample of 17 Norwegian floating net systems (modified after the Norwegian School of Business Administration, 1971).

Y = Capital cost per unit capacity ($£ \times 10^{-2}/ft^3$)
X = Rearing volume ($ft^3 \times 10^2$)

$Y = 39.84X^{-0.6}$
$r = 0.75$ $p < 0.001$

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$0^{-2}/ft^3)$

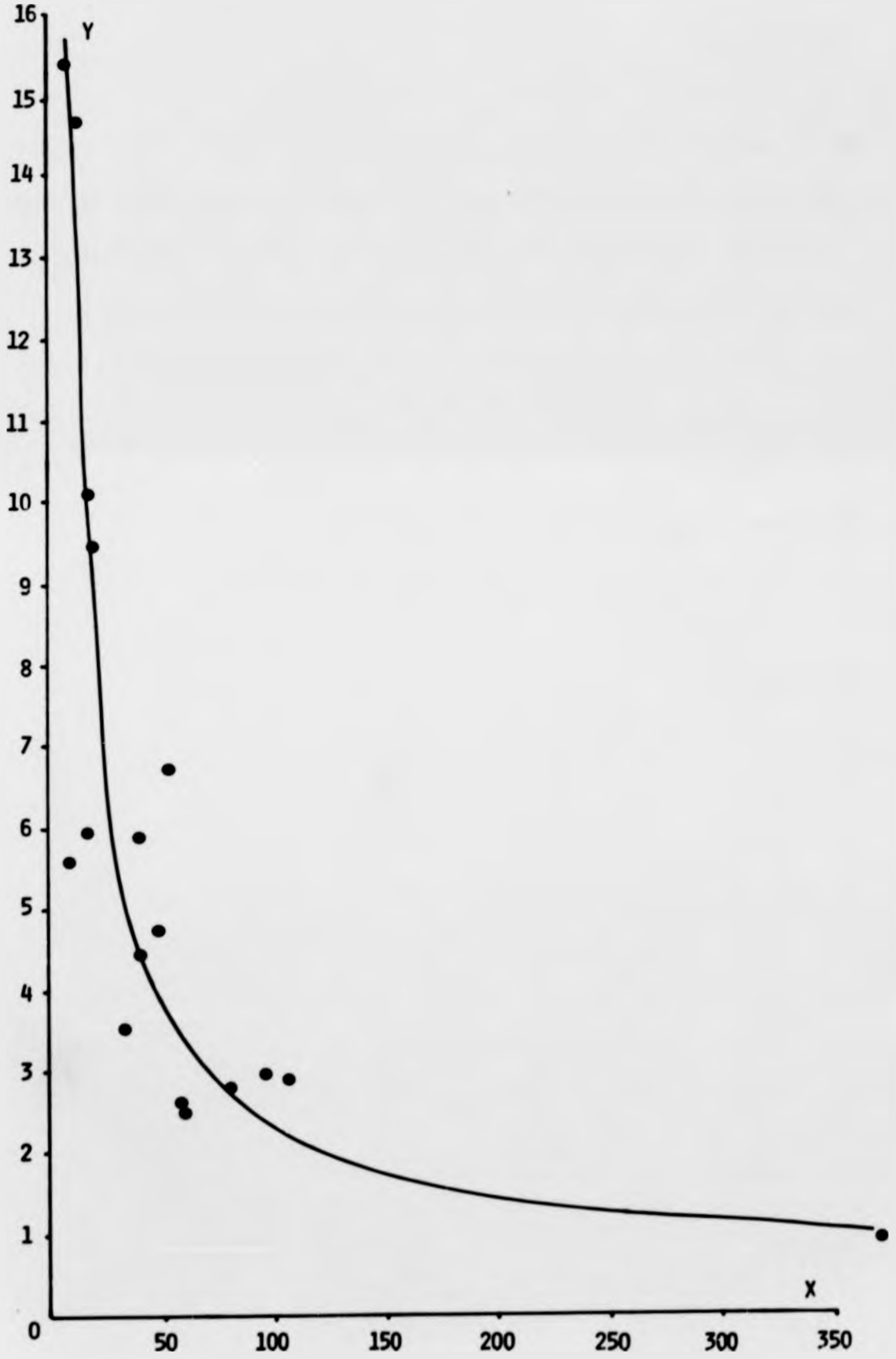

FIGURE 43

Relationship between total capital cost and maximum production capacity for a sample of nine Norwegian trout farms using fixed sea enclosures. Data derived and modified from the Norwegian School of Business Administration (1971).

Y = Total capital cost (£ x 10^3)
X = Maximum production capacity (tons)

$Y = 0.122\ X + 1.102$
$r = 0.84$ $p > 0.005$

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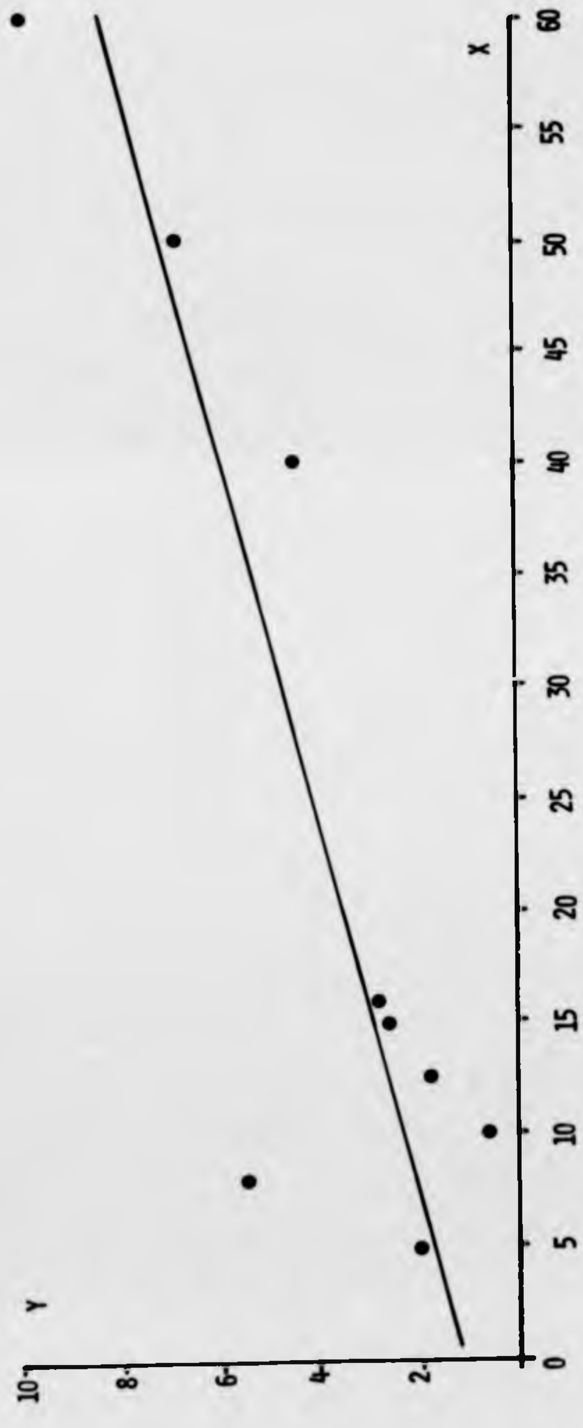

brick, inflatable Butyl etc. and screens are usually of cast-iron. Inlet channels may be excavated earth, concrete etc., or may be piped. Unit costs of pipes are variable (Table 42) and there are usually quantity discounts available. It is not possible to give cost statistics for piping, valves, etc. at fish farms, as these are dependent upon the design, site plan, etc.

TABLE 42

Unit costs of Piping

Diameter (Inches)	Retail Price/foot of Warin* pipes (£)	Retail Price/foot of Polyorc pipes (£)
6"	0.46p.	0.37p.
8	0.70	0.56
9	0.88	0.70
10	1.05	0.84
12	1.35	1.08
14	1.83	1.46
16	2.12	1.70
18	2.79	2.23
20	-	2.37
22	-	2.87
24	-	3.41

* (Yorkshire Imperial Plastics)

9.5.5 Buildings

The cost of shelter for hatchery, processing machinery and pump is described elsewhere. Office accommodation and Food Stores may be provided and are often prefabricated in construction. Two Scottish farms have erected such wooden buildings with their own labour. Total cost (approx. 150 sq.ft. floor; incl. drainage) was ca. £1,600 excl. of labour. Alternatively, building contractors may be hired; this is commonly undertaken for construction of pumphouses. Current price quotations for the various operations are as follows (Macfarlane, personal communication):

	£
Blocks for building	3/yd^2
Base	2/yd^2
Excavation (no rock)	0.50p./yd^3
Roof	1.25p./yd^2

9.5.6 Plant and Machinery

Investments may be made under the following categories (i) Pumping equipment, (ii) Processing equipment, (iii) Freezing equipment and (iv) Others.

(i) Pumping equipment

The main investments are in pumps and pumphouse.

Pumps:

It is standard practice to purchase a standby pump in case of emergency breakdown. The two pumps are usually either electric (with a diesel generator standby power supply) or one electric and one diesel. The latter system has a lower capital cost but requires more maintenance than two electric pumps; deliveries of diesel fuel are also required and diesel pumps are not favoured by trout farmers (Macfarlane, personal communication). Table 43 and Fig. 45 indicate the influence of power rating (or equivalent) on capital cost of pumps. It will be observed that bronze pumps (used for sea water) have higher costs than cast-iron pumps (which corrode with sea water). Outlays for cable, isolator box, D.L.L. starter (or switchboard) may or may not be included in the cost of the pump. Diesel generators retail at £1,700 - £2,500 at the present time (Macfarlane, personal communication). The pumps and fittings may be depreciated over 3 years. The relationship between power rating of pumps at different heads with waterflow rate, and hence

FIGURE 44

The relationship between capital investments for pumping and maximum annual production on nine land-based Norwegian trout farms. Data is derived and modified from the Norwegian School of Business Administration (1971).

Y = Capital cost of pumps and associated buildings and equipment

X = Maximum annual production (tons)

$Y = 0.605X - 0.746$

$r = 0.97$ $p < 0.001$

FIGURE 45

The relationship between capital cost of pumps and the advertised pump rating, for a sample of 13 pumps commercially available in the U.K. This sample includes eight bronze (marine) and cast-iron electrical pumps, and also five diesel pumps.

Y = Capital cost (£)

X = Pump rating (kW)

$Y = 56.67X + 143.46$

$r = 0.90$ $p < 0.001$

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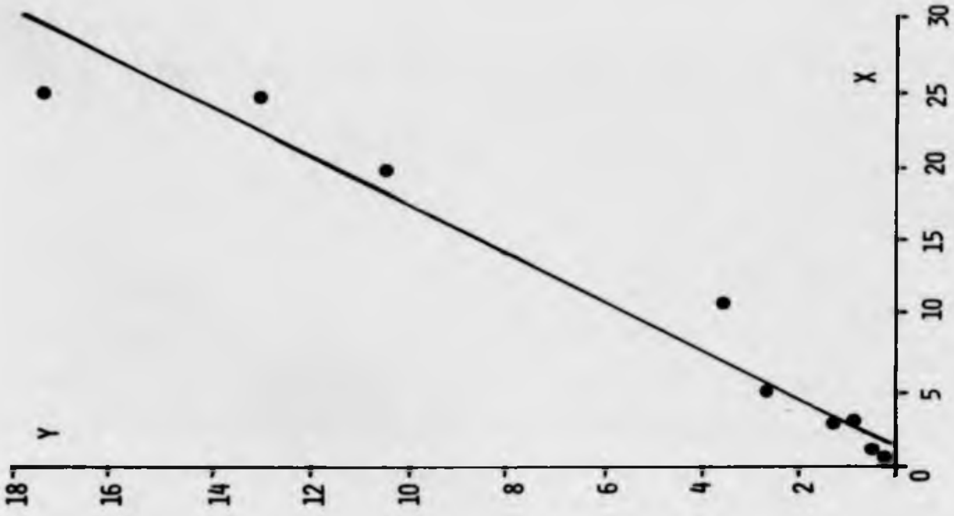

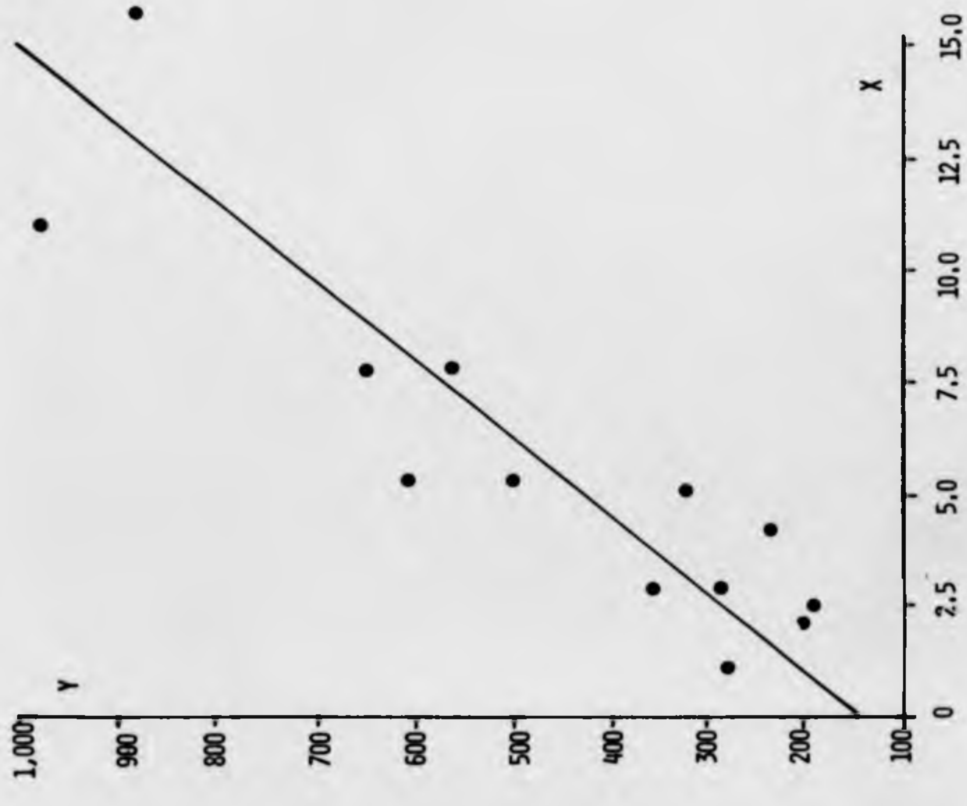

pumping cost per unit of fish production is discussed in Ch. 10. Norwegian data indicates an approximately linear relationship between pumping investments and maximum annual production (Fig.44)

TABLE 43

Capital Cost and Power Rating for Pumps

Manufacturer	Description	H.P.	Kw	Price (£)
1. Sumo	Aluminium		2.45	188
2. "	"		4.15	235
3. J. Beresford		4	2.9	358
4. " "		16	11.0	975
5. Godwin	Diesel pump	4	(2.9)	287
6. "	" "	21.5	(15.7)	879
7. Flygt pumps	Complete: on-line	7	5.06	320
8. " "	" "	3	2.17	198
9. Sumo	Bronze(seawater)	7.4	5.36	605
10. "	Cast-iron	7.4	5.36	500
11. "	Bronze(seawater)	10.7	7.75	649
12. "	Cast-iron	10.7	7.75	564
13. "	Bronze(seawater)	1.52	1.1	281

Pumphouse:

Outlays are for excavation, for the base and for the building and roof(Section 9.5.5. Buildings). Construction is more costly if it is a seashore location (with tidal changes in water level), if rock is discovered and if "cave-ins" occur during excavation. The cost of the pumphouse may be depreciated over 10 - 20 years. One site (Gateway West Argyll) which had budgeted £2,500 for excavation and forming the base for a pumphouse under contract, required outlays of ca. £9,000 because of problems with rock.

Summary of Capital Investments for Pumping:

These may be illustrated by the three Scottish farms which pump.

(a) Gateway West Argyll: Pumping head = 32'; Max. production = 70 tons. Capacity: 2 electric pumps - 7,500 g.p.m.
2 electric pumps and 1 diesel - 10,500 g.p.m.

Capital cost of pumps:	i) electric	=	£1,000
	ii) diesel	=	£800
	iii) flygt (15 H.P.)	=	£780
Capital cost of pumphouse:			
	i) Excavate and form base	=	£9,000
	ii) Pumphouse and roof	=	£720
	Total investment	=	£12,300

(b) Highland Trout: Pumping head = 42'; Max. production = 12 tons p.a. Capacity of all 3 pumps = 3,200 g.p.m.

Capital Cost of pumps:	1) Lister diesel (16 H.P.)	=	£850
	ii) Single phase electric (6 H.P.)	=	£200
	iii) Single phase electric (8 H.P.)	=	£240

Capital cost of pumphouse (built by farm staff and labour charge not specified) - raw materials = ca. £500.

(Excl. labour) total investment = ca. £1,800

(c) Kenmure: Pumping head = 9'; Max. production = 80 tons p.a. Capacity of 2 pumps = ca. 8,000 g.p.m.

Total capital cost of pumps and pumphouse = £10,000

Pumping investment costs as a fraction of total initial investment costs for a, b and c are 16%, 5% and 47% respectively.

The Norwegian School of Business Administration (loc.cit.) gave data on seawater pumping investments in Norway. These have been modified and summarized graphically by Fig. 46. which appears to indicate a higher capital cost for farms which

FIGURE 46

Relationships between total capital investment and maximum annual production for land-based Norwegian trout farms which utilise (a) gravity-fed water and (b) pumped water. Data is derived and modified from the Norwegian School of Business Administration (1971).

Y = Total capital cost (£ x 10^3)
X = Maximum annual production (tons)

Sample A (6 farms): using gravity-fed water
$Y = 0.278\ X + 6.398$
$r = 0.86$ $p < 0{\cdot}02$

Sample B (7 farms): using pumped water
$Y = 0.820\ X - 1.953$
$r = 0.99$ $p < 0{\cdot}001$

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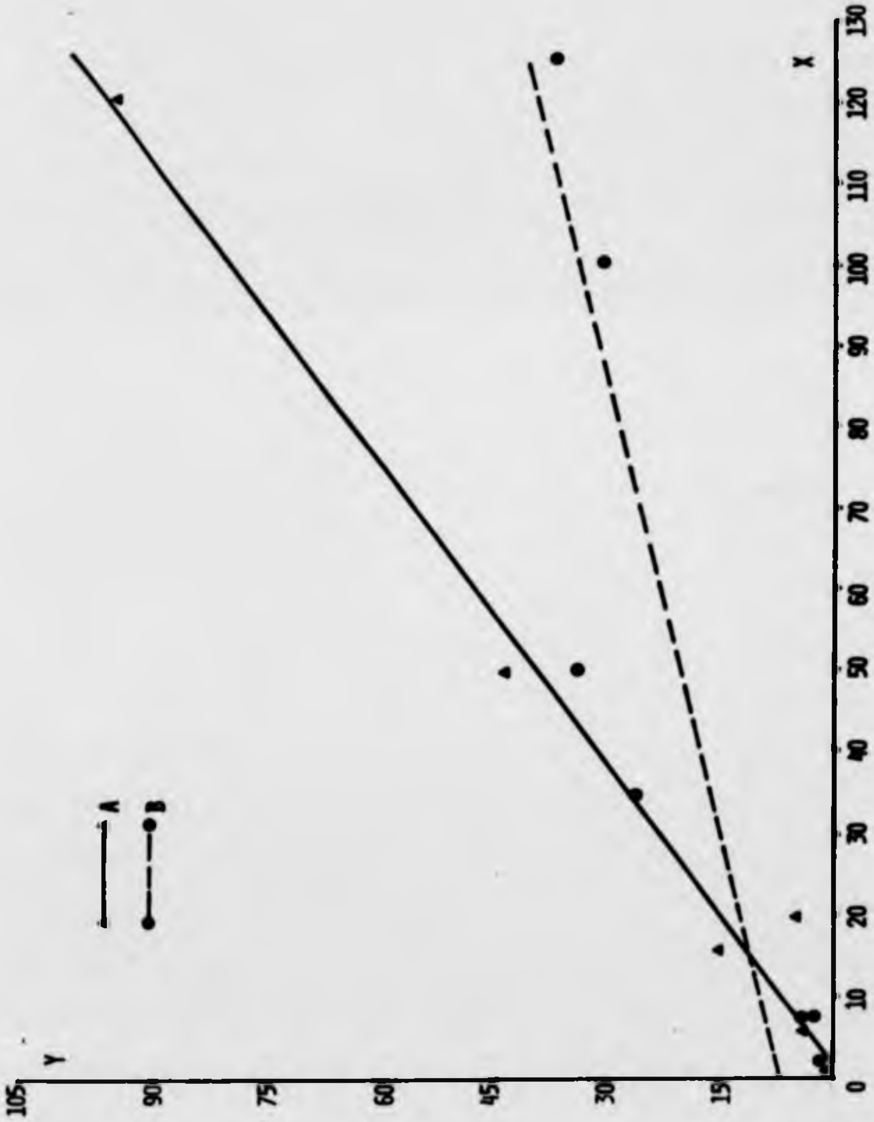


pump water compared with use of gravity feed, i.e. land-based farms which pump seawater instead of wholly freshwater farms. The Scottish farms(a) and (c) appear to have a considerably lower investment in pumps relative to annual production. The latter pump freshwater and it could be that capital costs for seawater pumping are larger. Sedgwick (personal communication) claimed that cost was a major reason for the closure of some Norwegian pumping farms but further statistics are not available.

(ii) Processing equipment

In Denmark, investment is required in mincing machinery for trash fish food. This usually has a concrete base and brick shelter and the total cost is unlikely to exceed £1,000 (Jansen, personal communication). The capital cost of machinery for mincing or for processing the finished product may be depreciated over 3 - 10 years. Most U.K. farms sell trout unprocessed. The capital cost of one machine (Bader) suitable for gutting and gilling up to 1,000 tons p.a. installed at a Scottish trout farm (Gateway West Argyll) was £6,000 in 1972.

(iii)Freezing equipment

Either Plate or Blast freezers may be used.

Plate freezers :

A horizontal plate freezer with an effective plate area of 18.6 ft^2 (61" x 44"; 12 - 15 stations) would require ca. 1½ hours freezing time for a load of 150 stone (2,100 lbs.) depending on the block thickness. A machine of these specifications at a rating of 100 H.P. is currently available at a retail price of £14,000 - £15,000 installed, and would require a minimal volume of water for recirculation (Morrice, personal communication)

Blast freezers;

A 50 H.P. freezer is currently available at a retail price of £6,000 and is capable of blasting at a rate of 40 stone/hour (560 lbs./hour) (Morrice, personal communication).

(iv) Building, etc.

Accommodation is required for the capital equipment involved in processing. Other items required include some form of weighing and/or grading apparatus, and a cold store for maintaining the frozen product. A building to contain a plate freezer and cold store facilities for 1 ton would require a capital cost of ca. £4,800 (incl. concrete base) @ £4/ft^2, and probably ca. £6,000 (incl. cold store, weighing equipment, fittings) (Macfarlane, personal communication).

Total capital costs for the operations of gutting and gilling, blast freezing and holding one ton in store would be ca. £18,000, and, if plate frozen was undertaken ca. £26,500. Capital costs would be reduced if any or all of these operations were either (a) omitted, (b) contracted out (c) performed manually, although all other things being equal, it is likely that this might entail incremental operating costs. Processing and freezing equipment may be depreciated over a period of 3 - 10 years.

(v) Miscellaneous

Other items of capital expenditure might include: Access roads and perimeter fence; Vehicles - cars, trucks, boats; Equipment - grading, seines, aerators, meters, etc.

Detailed capital costs are not available. Miscellaneous costs are variable, dependent upon site conditions, etc., and individual requirements of the farm. Scottish trout farms usually possess one car and one truck (for transporting product, etc.), with a total capital cost of *ca.* £4,000 and a depreciation period of *ca.* 5 years. Macfarlane (personal communication) presented the following capital costs for a farm producing 100 tons of trout per annum, exclusive of costs considered hitherto:-

	£
Vehicles	3,300
Power installation (floodlamps, connections, etc.)	4,200
Roads (main road and tracks between raceways)	3,000
Stores (general)	1,200
Fencing	2,000
	£13,700

These 'other costs' represented 16% of the total capital cost of a projected raceway farm, of which costs and design were based upon pre-existing farms in the U.K. Only one item (roads) would be likely to incur a lower capital cost on an alternative system (earth ponds). These costs are likely to increase *pro rata* with increased scale.

9.6
Total Capital Costs

One may attempt to predict the total capital cost required for construction of a fish farm at a particular site by consideration of historical data for similar systems. Such data was, however, difficult to obtain, particularly for certain systems, e.g. floating nets, which are not commonly used at the present time in Scotland. Data was available for most of the components of capital cost and could therefore be aggregated to derive total capital costs. Comparisons might then be made between (a) aggregated total capital cost data and (b) historical costs of total investments where known, the results of which might then be of use for predictive purposes.

9.6.1 Aggregated Costs

Capital costs of holding facilities for various production capacities may easily be computed from the foregoing data, summarized in Table 44 , if a linear relationship between capital cost and usable volume is assumed. Of the capital requirements for other items previously considered, some, e.g. excavation, are unique to a particular site and therefore less amenable to prediction. Certain items, e.g. buildings for offices and pumps, are likely to show economies of scale in capital cost, and certain specialized items, e.g. processing equipment, may be to some extent indivisible. Sufficient information is available to make attempted predictions of total capital cost ranges by aggregation of cost components. For particular systems, this is simplified by the absence of certain components; thus in the case of floating systems, it is not necessary to invest in site purchase (usually), or dams, pipes and valves. Aggregation of these various cost components to give a compre-

TABLE 44

Summary of predicted unit costs for depreciation of different holding facilities, likely depreciation period, and extrapolated capital costs at two levels of annual production capacity

Holding Facility	Depreciation period (yrs.)	Depreciation cost/ton/yr. (£)	Capital Cost at 2 levels of production capacity (£ x 10^3) 15 tons p.a.	100 tons p.a.
1 Earth ponds	10	9	1.350	9.000
2 Narrow earth raceways	5	16	1.200	8.000
3 Wide earth raceways	5	10	0.750	5.000
4 Brick raceways	10	27	4.050	27.000
5 Fibreglass-cement raceways	10	29	4.350	29.000
6 Concrete raceways	10	39	5.850	39.000
7 Polythene-lined earth ponds	10	9	1.350	9.000
8. Faunliner-lined earth ponds	10	17	2.550	17.000
9 Butyl-lined earth ponds	10	19	2.850	19.000
10 Fibreglass cement circular tanks	10	41	6.150	41.000
11 Fibreglass circular tanks size 1	10	52	7.800	52.000
12 Fibreglass circular tanks size 2	10	24	3.600	24.000
13 Fibreglass circular tanks size 3	10	35	5.250	35.000
14 Fibreglass circular tanks size 4	10	22	3.300	22.000
15 Concrete formed circular tanks	10	46	6.900	46.000

continued .....

TABLE 44 (continued)

Holding Facility	Depreciation period (yrs.)	Depreciation cost/ton/yr. (£)	Capital Cost at 2 levels of production capacity (£ x 10^3)	
			15 tons p.a.	100 tons p.a.
16 Preformed Silo-stave circular tanks size 1	10	26	3.900	26.000
17 Preformed Silo-stave circular tanks size 2	10	17	2.550	17.000
18 Preformed Silo-stave circular tanks size 3	10	15	2.250	15.000
19 Floating systems size 1	3	24	1.080	7.200
20 Floating systems size 2	3	5	0.225	1.500
21 Floating systems size 3	3	7	0.315	2.100
22 Floating systems size 4	3	12	0.540	3.600
23 Enclosures	10 & 3(net)	10	0.850	5.700

N.B. This assumes a linear relationship between capital cost and rearing volume, an assumption which is more probable for the excavated than for the fabricated facilities.

hensive range of total capital cost for each main system at four levels of production capacity was performed (Tables 45 - 48) and included consideration of the effect on cost of investments in pumping and processing.

9.6.2. Actual costs and comparisons

The total capital costs of the Scottish trout farms from which data was available indicate a reasonable agreement, when compared with the values predicted by aggregation (Table 49)

Two farms (College Mill and Cantray Mill) of low investment are below the predicted cost range for their capacity and system. Both these farms (like most small trout farms) were constructed by the owner; it is likely that labour was not charged at opportunity cost rates (on which the aggregated cost predictions were based).

Total capital cost data was also obtained for a sample of seven earth pond systems in Denmark, England and Ireland, and was used to construct a graph of capital cost plotted against production capacity (Fig. 40). This latter sample also indicates a reasonable agreement with predicted values, although the upper end of ranges for a given capacity tends to exceed the upper predicted values, e.g. 2 farms, each of 100 tons p.a. capacity, had total capital costs of £36,000 and £63,000, whereas the equivalent predicted range was £28,000 - £44,000. In comparing observed and predicted values for total capital costs, it would seem possible that the range of total capital costs for historical investments, at a given capacity of production, tends to be broader than the range predicted by aggregation. Another consideration is the breakdown of the components of total costs of historical investments.

Table 45

Summary of total capital cost structure for farms with an annual production capacity of 15 tons

A.

Investment (excl. holding facility)	Range of Capital cost ($£ \times 10^3$ unless otherwise stated)
Hatchery and early rearing system	1 - 2
Land and excavation	0-10% T.C.C. (0)
Miscellaneous (vehicles etc., incl. mincing machinery)	2 - 4 (2 - 3)
Buildings (Food store and office)	1 - 2
Contingencies (incl. Dams, Pipelines and Valves)	10% T.C.C.
Pumps and pumphouse	1 - 16

B.

System	Range of total capital cost ($£ \times 10^3$)	T.C.C. + range of total capital cost for pumping all water ($£ \times 10^3$)
Earth ponds & raceways	6 - 11	7 - 27
Fabricated raceways	9 - 17	10 - 33
Lined earth ponds	6 - 13	7 - 29
Circular tanks	7 - 19	8 - 35
Floating	4 - 9	5 - 25
Enclosures	6 - 9	7 - 25

N.B. (i) T.C.C. = Total capital cost

(ii) Figures in parentheses indicate most likely values on ranges of values.

Table 46

Summary of total capital cost structure for farms with an annual production capacity of 50 tons

A.

Investment (excl. holding facility)	Range of Capital cost ($£ \times 10^3$) unless otherwise stated)
Hatchery and early rearing system	1 - 4
Land and excavation	1-10% T.C.C. (0)
Miscellaneous (vehicles etc., incl. mincing machinery)	6 - 8 (3)
Buildings (Food store and office)	2 - 3
Contingencies (incl. Dams, Pipelines and Valves)	10% T.C.C.
Pumps and pumphouse	4 - 18
Processing plant and equipment	18 - 27

Table 46

Summary of total capital cost structure for farms with an annual production capacity of 50 tons

B.

System	Range of total capital cost (£ x 10^3)	T.C.C. range of total capital cost of pumping all water (£ x 10^3)	T.C.C. range of total capital cost of processing (£ x 10^3)	T.C.C. cost of pumping cost of processing (£ x 10^3)
Earth ponds and raceways	14 - 24	18 - 42	32 - 51	36 - 69
Fabricated raceways	26 - 42	30 - 60	44 - 69	48 - 87
Lined earth ponds	17 - 30	21 - 48	35 - 57	39 - 75
Circular tanks	20 - 50	24 - 68	38 - 77	42 - 95
Floating	8 - 15	12 - 33	26 - 42	30 - 60
Enclosures	10 - 14	14 - 32	28 - 41	32 - 59

Table 47

Summary of total capital cost structure for farms with an annual production capacity of 100 tons

A.

Investment (excl. holding facility)	Range of Capital cost (£ x 10^3 unless otherwise stated)
Hatchery and early rearing system	5 - 8
Land and excavation	1 - 10% T.C.C. (0)
Miscellaneous (vehicles, etc., incl. mincing machinery)	12 - 15 (5)
Buildings (Food store and office)	2 - 4
Contingencies (incl. Dams, Pipelines and Valves)	10% T.C.C.
Pumps and pumphouse	7 - 21
Processing plant and equipment	18 - 27

Table 47

Summary of total capital cost structure for farms with an annual production capacity of 100 tons

B.

System	Range of total capital cost ($£ \times 10^3$)	T.C.C. range of total capital cost of pumping all water ($£ \times 10^3$)	T.C.C. range of total capital cost of processing ($£ \times 10^3$)	T.C.C. cost of pumping cost of processing ($£ \times 10^3$)
Earth ponds and raceways	28 - 44	35 - 65	46 - 71	53 - 92
Fabricated raceways	52 - 80	70 - 107	59 - 101	77 - 128
Lined earth ponds	32 - 56	50 - 83	39 - 77	57 - 104
Circular tanks	39 - 96	57 - 123	46 - 117	64 - 144
Floating systems	15 - 26	33 - 53	22 - 47	40 - 74
Enclosures	20 - 25	38 - 52	27 - 46	45 - 73

Table 48

Summary of total capital cost structure for farms with an annual production capacity of 500 tons

A.

Investment (excl. holding facility)	Range of capital cost (£ x 10^3 unless otherwise stated)
Hatchery and early rearing system	14
Land and excavation	4 - 10% T.C.C. (0)
Miscellaneous (Vehicles etc., incl. mincing machinery)	60 - 75 (25)
Buildings (Food store and office)	6 - 12
Contingencies (incl. Dams, Pipelines and Valves)	10% T.C.C.
Pumps and pumphouse	30 - 45
Processing plant and equipment	21 - 30

TABLE 48

Summary of total capital cost structure for farms with an annual production capacity of 500 tons

D.

System	Range of total capital cost (£ x 10^3)	T.C.C. range of total capital cost of pumping all water (£ x 10^3)	T.C.C. range of total capital cost of processing (£ x 10^3)	T.C.C. cost of pumping cost of processing (£ x 10^3)
Earth ponds and raceways	120 - 177	150 - 222	141 - 207	171 - 252
Fabricated raceways	241 - 358	271 - 403	262 - 388	292 - 433
Lined earth ponds	142 - 237	172 - 282	163 - 267	193 - 312
Circular tanks	175 - 437	205 - 482	196 - 467	226 - 512
Floating	61 - 95	91 - 140	82 - 125	112 - 170
Enclosures	80 - 87	110 - 132	101 - 117	131 - 162

Table 49 Total capital costs of 5 Scottish trout farms in relation to production and capacity, compared with capital costs of similar systems predicted by aggregation of costs.

Farm	System	Max. annual production achieved (tons)	Probable annual production capacity (tons)	Approx. total capital costs (£ x 10^3)	Total capital cost: predicted range for equiv. system (£ x 10^3)
Cantray Mill	Earth raceways	12	15	3.7	6 - 11
College Mill	Earth ponds	11	15	4.1	6 - 11
Gateway West Argyll	Brick raceways	70	150	118.1	116 - 192
Highland Trout	Concrete raceways	12	50	55.4	30 - 60
Kenmure Fisheries	Earth ponds	30	80	33.3	28 - 52

N.B. All costs have been converted to a common time-base (March, 1973)

Unfortunately, itemized data was obtained from only one Scottish farm (Table 50). In this case, 46% of total capital cost was for pumping with the costs of holding facilities the only other large item (33%).

By contrast, predicted values tended to show a greater proportion of total capital cost comprised of miscellaneous items (not greater than 50% for earth ponds; greater than 50% for some floating systems and enclosures).

Table 50 Capital Cost Structure of Kenmure Fisheries

Capital cost component	Capital Cost (£ x 10^3)	Cost of component as % of total capital cost
Hatchery & early rearing	3.9	12
Plant & machinery	15.4	46
Site purchase and excavation	-	-
Holding facility	10.8	33
Dams, pipes and valves	-	-
Buildings	1.6	5
Miscellaneous	1.6	5

Both aggregated and actual costs would otherwise indicate that the total capital costs of systems which utilise fabricated raceways and circular tanks are highest of those considered, and that those of systems which utilise floating systems and enclosures are lowest; the costs for earth ponds and raceways and for lined earth pond systems are intermediate in range, with the former rather less than the latter.

9.7 Government Assistance

In order to assist the regional economy in Scotland (and in some other parts of the U.K.), the Government is prepared, under certain circumstances, to offer assistance to companies, or individuals, wishing to invest in fish farms. This can take the form of technical assistance and also of financial aid, which is usually mediated at the present time by either the Highlands and Islands Development Board (HIDB), the Department of Trade and Industry (DTI), or the relevant local Authority, or more than one of these bodies.

For financial assistance from the HIDB, it is necessary for the investment to take place within the six counties of Argyll, Caithness, Inverness-shire, Ross and Cromarty, Sutherland and Zetland. Such assistance may be in one of several forms, e.g. Special Grants, Loans, and Equity capital, whose sum is commonly up to 50% of total initial requirements with a theoretical ceiling of 70% (i.e. the HIDB offering finance on a £ for £ basis up to 50% of fixed and first year working capital requirements, of which up to 25% may be as grant aid and up to 25% as loan). Unlike special grants, loans are usually closely tied to the consequent employment factor at the proposed site. Such loans are usually at a current interest rate of 7½% but may occasionally be free. Repayment may be deferred for an agreed period, e.g. related to the production cycle time; in this case, the accumulated interest is often capitalized (McPhail, personal communication).

Financial assistance to investment in buildings, plant and machinery in Scotland may be provided by the DTI. Assistance, if given, is generally in the form of grants, which are commonly

20% of the capital cost. In such cases, the investor may also be permitted to write off the entire capital outlay in the first year (it is not yet clear whether HIDB special grants may be treated in the same way or whether they will be taxable, e.g. if grant is 20%, whether only an 80% initial write-down will be permitted).

The influence of these considerations upon the profitability of fish farms is examined later under 'Financial Assessment' (Chapter 11).

9.8 Summary

Capital costs in trout farming may be classified into four functional types:

i) capital cost of a hatchery
ii) capital cost of an early-rearing facility
iii) capital cost of an on-growing facility
iv) capital cost of plant and machinery

Depending upon the operations of an individual farm, investment is required under one or more of such categories. For a farm which undertakes at least i, ii, and iii, as a proportion of total capital costs, hatchery costs are likely to be insignificant and early-rearing costs to be less than 10%, except where annual production is very low (10 tons). Capital costs for pumping vary considerably depending upon requirements and site conditions, and may on occasion be the largest element of total capital cost. Capital costs for pumphouses and for processing are likely to exhibit economies of scale. The scope of investments required for on-growing depend partly upon the system utilised, and comprise six main elements:

i) Site Purchase
ii) Excavation

iii) Holding Facility
iv) Dams, Pipes and Valves
v) Buildings
vi) Miscellaneous

Of these six cost components, where relevant it is possible to predict the cost of holding facilities for various capacities if one assumes an effectively linear relationship between their capital cost and production capacity.

However, rearing volume, which is directly proportional to production capacity, is not necessarily related in a linear fashion to capital cost. Although this may be the case for excavated systems, a $2/3$ power relationship might be expected for fabricated systems. There may also be economies of scale for certain other components of total capital investment.

Nevertheless, an attempt was made to aggregate the cost component predictions in order to derive a predicted range for total capital cost under various circumstances. This was undertaken and such predictions showed reasonable agreement with observed total capital cost data except at very low production capacities for earth ponds and raceways. Commencing with the lowest investment per unit production capacity, the order of ascending cost was (i) Floating systems and Enclosures, (ii) Earth ponds and raceways, (iii) Lined earth ponds, (iv) Fabricated raceways and circular tanks.

It is possible for investors within the H.I.D.B. area to obtain 50% of fixed and first year working capital requirements in the form of grants (not greater than 25%), loans, equity, etc. Outside the H.I.D.B. area, some assistance may be available, notably grants for plant and machinery from the D.T.I., which are commonly 20% of capital cost.

CHAPTER 10

OPERATING COSTS

10.1 Introduction

Operating costs in Trout farming comprise various elements, including both fixed and variable costs.

I. FIXED

i) capital charges of fixed investment

II. VARIABLE

i) feed costs

ii) labour costs

iii) losses and insurance costs

iv) power costs

v) selling costs (incl. transport)

vi) maintenance costs

vii) costs of ova

viii) administration and miscellaneous (some of which may be fixed costs).

The capital costs and feed costs have already been discussed. The remaining elements of operating cost, i.e. the variable costs will be considered individually (excluding feed) and as a whole (including feed).

10.2 Labour costs

Trout farms in Scotland have been operating for insufficient time to provide much information about the cost of labour. Experience elsewhere would indicate, however, that this problem is influenced by several factors.

10.2.1 Scale

Data was collected from a sample of 11 farms in the U.K., Ireland, Denmark and Italy, all of which undertook hatchery, early-rearing and on-growing operations (Table 51). This may be compared with a sample of 24 farms in Norway, the nature of whose operations is unknown except that some were operated on a part-time basis (e.g. subsidiary to fishing activities) and labour was charged accordingly (Table 52). The mean values of production per employee per year (i.e. production per man-year) for the 'international' and Norwegian samples are 19.6 tons and 9.1 tons respectively, which may be related to the mean values of maximum annual production, i.e. 78.6 tons and 18.8 tons respectively. This might indicate that there are economies of increased scale with respect to labour.

The relationship between production per employee and the number of employees (Fig.47a) would tend to confirm this for farms in the international sample employing more than one man; for the Norwegian sample, the individual output per employee showed considerable variation and insufficient data on large farms was available to draw meaningful conclusions. Farms with a large annual production are more likely to undertake ancillary operations, e.g. processing, which require additional units of labour. However, the possible diseconomies of scale which might be expected to result are not apparent in the relationship between maximum annual production and number of employees (Fig.47b), notwithstanding the data inadequacies.

Omission of certain steps of the production cycle is likely to reduce labour demands. The practice of buying-in fingerlings, omitting early-rearing stages, apparently permits labour economies on earth pond farms (Fig. 48).

Table 51

Labour requirements in relation to maximum annual production on 11 trout farms

Maximum annual production (tons)	Number of employees	Production per employee (tons) per year
10	1.5	6.7
7	2.0	3.5
22	2.5	8.8
25	2.0	12.5
30	2.0	15.0
40	2.0	20.0
70	4.0	17.5
70	3.5	20.0
150	4.0	37.5
300	7.0	42.9
140	4.5	31.1

Table 52

Labour requirements in relation to maximum annual production on 24 Norwegian trout farms (data modified from the Norwegian School of Business Administration, 1971).

Maximum annual production (tons)	Number of employees	Production per employee (tons) per year
70	3.0	23.2
5	1.0	5.0
70	3.3	21.4
15	2.5	6.0
60	4.0	15.0
0.7	0.1	7.0
10.0	1.5	6.7
11	1.0	11.0
25	2.5	10.0
10	2.5	4.0
2	1.0	2.0
3	0.75	4.0
45	3.5	12.8
3	1.0	3.0
5	1.0	5.0
10	1.0	10.0
30	3.0	10.0

52
Table/ (continued)

Maximum annual production (tons)	Number of employees	Production per employee (tons) per year
16	1.6	10.0
8	1.0	8.0
16	1.5	10.7
11	1.0	11.0
7.5	1.3	5.6
10	1.0	10.0
8	1.0	8.0

FIGURE 47

Relationship between maximum annual production and labour requirements for two samples of trout farms.

a) Y = Maximum annual production (tons)

X = Number of employees per annum

Sample A = 11 farms in U.K., Ireland, Denmark and Italy

$Y = 6.7X^2 - 1.8X$

Sample B = 24 farms in Norway (data from Norwegian School of Business Administration, 1971).

Y = [illegible] + 3.[illegible]X

b) Y = Production per employee per annum

X = Number of employees per annum

Sample A (as above)

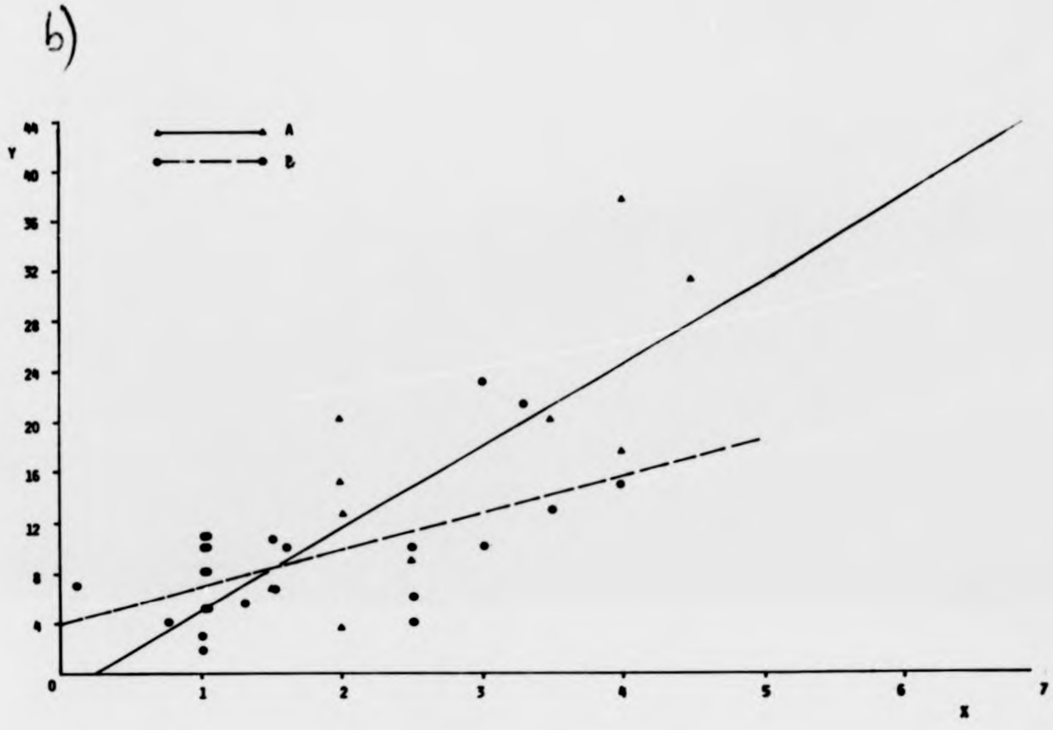
$Y = 6.71\ X - 1.75$

$r = 0.86$ $p > 0{\cdot}001$

Sample B (as above)

$Y = 3.03\ X - 3.96$

$r = 0.61$ $p > 0{\cdot}005$


b)
Y
44
40
36
32
28
24
20
16
12
8
4
0
1
2
3
4
5
6
7
X
A
B

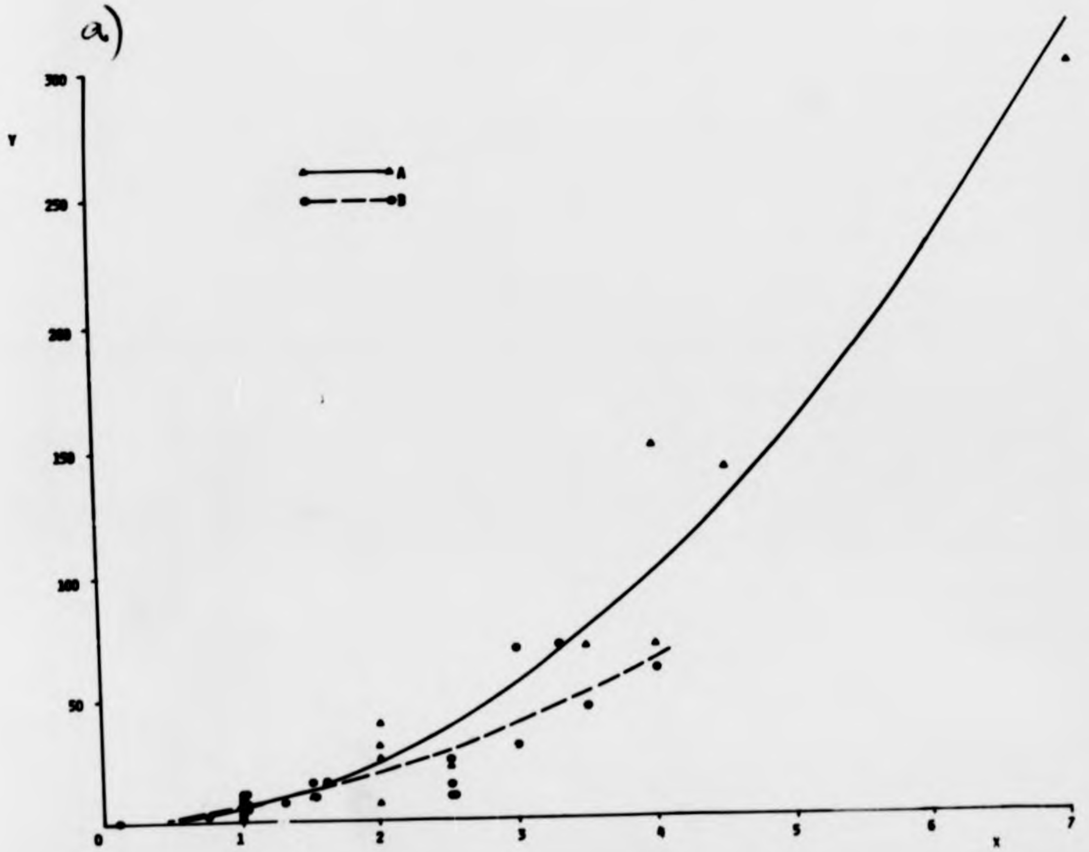

a)
Y
300
250
200
150
100
50
0
1
2
3
4
5
6
7
X
A
B

FIGURE 48

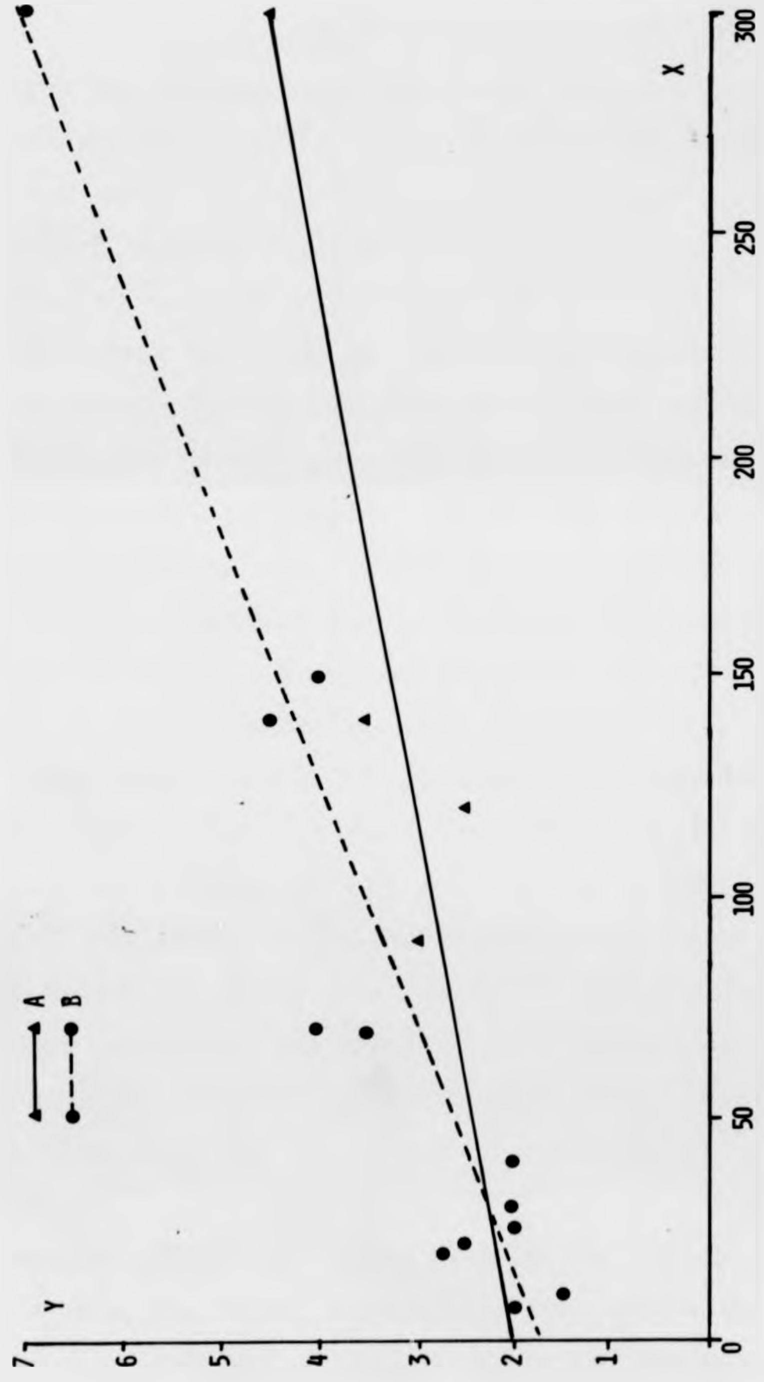
The relationship between labour requirements and maximum annual production for trout farms which
a) buy-in fingerlings annually and do not operate a hatchery or early-rearing facility, and
b) undertake all aspects of the production cycle (including hatchery and early-rearing operations)

Y = Number of employees per annum
X = Maximum annual productions (tons)

Sample A (4 farms): farms which buy-in fingerlings
$Y = 0.01 X + 2.04$
$r = 0.90$ $p < 0.05$ 5%

Sample B (12 farms): farms which undertake all aspects of production cycle
$Y = 0.18 X + 1.79$
$r = 0.96$ $p < 0.001$

s and
hich
perate
cycle
tions)
gerlings
all aspects



10.2.2. Season

If, as usual, there is a seasonal pattern of production, then it is likely that labour requirements will fluctuate seasonally. In Denmark, certain farms recruit additional labour during the Summer, e.g. two farms with an annual production of 80 tons and 120 tons required two workers during the winter and three during the summer (see Figure 49) (Jensen, personal communication).

10.2.3 Husbandry systems and automation

It is possible to automate certain operations (e.g. grading) which should reduce labour requirements. The feeding of wet food with increased bulk and difficulties of automation might be expected to result in greater labour requirements than for dry feed. In Denmark, the production of 15 tons/man year is considered to be a standard for profitable operation (Berge, loc. cit.) and labour costs are approximately equal to the sum of all other operating costs excluding feed (Table 53). Some Norwegian farms have managed to produce corresponding levels of production also using wet feed (Berge, loc.cit.).There is no evidence that the feeding of dry food in the U.K. has caused a substantial reduction in labour requirements below these levels. However, it would seem probable that, under certain circumstances, automated dry feeding will permit economies in labour relative to wet feeding which will become increasingly significant with increase in annual production.

10.2.4 Others

The cost of labour for trout culture is likely to be influenced by the foregoing factors, which affect the demand for labour. An analysis of labour costs may be complicated further by factors such as:

FIGURE 49

Diagram to indicate the probable relationship between labour requirements and annual production for Danish trout farms, which undertake both hatchery and wet feeding operations.

Y = Number of employees per annum

X = Annual production (tons)

The stippled areas represent the 'step-up zones of annual production'. Depending upon the efficiency of manpower, at some level of production within these ranges, it is necessary for the farms to recruit an additional employee if an increment in production is required. Since there is a greater workload in summer than in winter, where possible certain farms annually recruit an additional employee for the former only. The broken line in the diagram indicates the nature of the relationship from November until April for those farms, with an annual production exceeding 70 tons, which obtain seasonal labour economies in this manner.

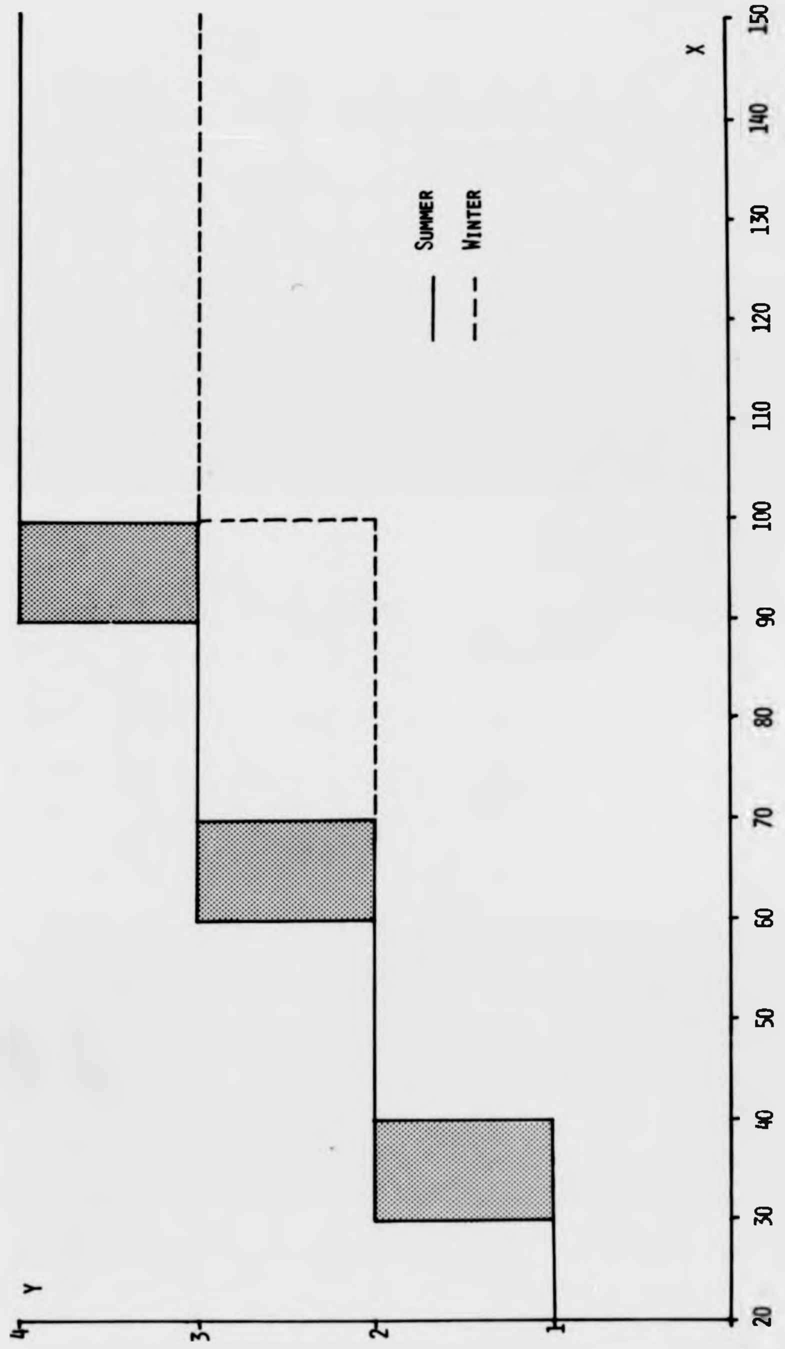

Y
4
3
2
1
X
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Summer
Winter

Table 53

Annual operating costs (exclusive of feed costs) as a percentage of total production costs at Forsøgsdambruget Brøns, Denmark: 1964 - 1968

Year	Cost of Wages as %age of total Annual Production Costs	Other operating costs (excl. feed, wages) as %age of total Annual Production costs
1964	25	23
1965	22	24
1966	25	20
1967	25	26
1968	29	24

i) the possibility that labour is not charged at opportunity cost rates, e.g. small farms may utilise family labour at deflated cost levels.

ii) the possibility that labour is hired in excess of its strict requirements, e.g. because of the existence of certain regional employment incentives.

Except for possible seasonal labour increments as described, units of labour, and hence annual labour costs, are indivisible. Therefore the relationship of labour cost with annual production is likely to exhibit a step progression (Fig. 49). For a given annual labour cost, other things being equal, it follows that the most economical use of labour is represented by the level of production to which output may rise before it becomes necessary to increase labour costs (excl. overtime). A component of labour cost may, however, be wholly or partially unrelated to the level of production, e.g. due to employment of a nightwatchman, directors, etc.

10.2.5 Wage levels

The wage levels at the Danish Experimental Trout Farm, agreed upon by the Danish Trout Farmers' Association were as follows in April, 1972:-

Fish-master - £2,200 per annum
Labourer - £1,400 per annum

The relationship of labour cost to production over a period of five years at the same farm is given in Table 54.
In the absence of information about (i) the number of employees during a given year (2 - 3), (ii) the profile of wage inflation, if any, during the period under review, it

Table 54

Production and labour statistics at Forsøgsdambruget: 1964-1968

Year	1964	1965	1966	1967	1968
Total production (tons)	47	61	53	69	61
Cost of labour (£/ton produced)	55	48	64	61	74
Labour cost as percentage of total production cost (%)	25	22	25	25	29

is difficult to make meaningful conclusions. Moreover, it is probable that particular circumstances (e.g. a high incidence of furunculosis disease in 1968) affected labour costs. Nevertheless the mean labour cost as a percentage of total production cost at Forsogsdambrugat (25%) may be compared with the value of 23% predicted by Macfarlane for a 50 ton p.a. production raceway farm; values of 17%, 15% and 12% for the same raceway system were predicted at production capacities of 100, 200 and 500 tons p.a. respectively (Macfarlane, personal communication). In the U.K., agricultural wage levels are those generally used as a basis for negotiating fish farm wages: currently £1,500 - £2,500 per head p.a.

10.2.6 Conclusions

On the above basis, the ranges of feasible labour cost at four levels of production at a Scottish site may be computed (Table 55), assuming that, if processing of the product is undertaken at the highest level (500 tons p.a.), with Bader processing equipment, it will entail basic costs of £20,000 and incremental labour costs of £14,000 (Macfarlane, personal communication).

Table 55

<u>Annual Labour Costs for U.K. Trout Farms at 4 levels of production</u>

Annual production level (tons)	15	50	100	500*
Probable range of annual labour cost (£)	1,500-2,500	3,000-7,500	4,500-12,500	?
Probable average annual labour cost (£)	2,000	4,000	6,000	34,00

* incl. processing.

10.3 Cost of Losses

10.3.1 Introduction

As with other activities involving the rearing of animal livestock, losses of stock may occur during the production process and these may achieve particular prominence in fish culture which has hence been termed a high risk activity (Sedgwick, 1970). Berge (1968) referred to this problem in the context of Norwegian trout culture and listed nine categories of such loss:

i) Climatic
ii) Pollution
iii) Fish enemies
iv) Silting, etc.
v) Faulty construction
vi) Wear and Age
vii) Breakdown
viii) Human Errors
ix) Miscellaneous (e.g. transportation, diseases, spawning)

The Norwegian Business School (1971) attempted to quantify the causes of such loss as follows:

i)	Disease	27.9%
ii)	Climate	18.6%
iii)	Faulty construction	16.3%
iv)	Pollution	9.4%
v)	Breakdowns	9.4%
vi)	Human errors	6.7%
vii)	Fish enemies	4.7%
viii)	Transport	4.7%
ix)	Wear and Age	0%

They also presented a table showing a wide range of losses at different fish sizes on different farms, of which the average loss from eyed egg to swimup stage was 36% and the average loss from swimup to summer stocking fish was 17%. Norwegian data refers mainly to marine systems, e.g. floating nets and enclosures. Small scale losses may be regarded as 'normal' and it is generally not easy to predict such losses at any stage or to predict the pattern of mortality over time. All other things being equal, the scale of overall losses at one farm is likely to reflect the degree of control exercised by the husbandry systems employed. It is probable that the highest losses occur in extensive systems where, e.g. it is difficult to prevent predation, and the lowest losses are likely to occur in small tanks where continuous observation is possible, i.e. a possible sequence with respect to losses:-

i) Extensive systems (high losses)
ii) Earth pond systems
iii) Raceway systems
iv) Tank systems (low losses)

Obviously, poor husbandry or the introduction of severe disease or a failure in pumps, filters, etc. could create large or even total losses in any one of these systems; such losses may be described as 'abnormal losses'.

10.3.2 Normal losses

Trout farms expect, and budget for, small-scale losses which may be regarded as a normal cost of production. If, as is usual, records of such mortalities are not kept, they are manifested by a reduced food conversion rate (i.e. based upon a liveweight gain which excludes the weight of mortalities), food conversion rates on dry diets including 'average' losses expected for earth pond systems are ca. 1.6 at unit weight of 0.5 lbs. (comparable standards for wet diets are complicated by the variability of the diet). By comparison, American fabricated raceway systems aim for mortalities not exceeding 15% from swimup until off the first fry diet, 5% of the residual until transferred to the raceway, and 2% of the residual until slaughtered at 0.5 lbs. (Macfarlane, personal communication). For 10,000 first feeding fry (Table 56) this pattern of losses would result in 7,914 fish at 0.5 lbs., whose feed cost would be £379, equivalent to £215 per ton liveweight gain; this represents an incremental cost per ton liveweight gain, due to losses, of £28 which is equivalent to an increase in food conversion rate from 1.3 to 1.5. It has been claimed (Shorthouse, personal communication) that circular fibreglass tanks (ca. 30' diameter) may be operated so as to achieve food conversion rates, including mortalities, of not less than ca. 1.3, i.e. comparable to experimental data (Trouw, loc. cit.). It might be that such results are obtainable under farming conditions only when a degree of natural feeding exists.

Therefore, it seems likely that, due to its effect on the magnitude of normal losses, the choice of husbandry system may influence the food conversion efficiency (uncorrected for losses), which might be not less than 1.3 for circular tanks, ca. 1.5 for fabricated raceways and ca. 1.6 for earth ponds. As well as the increased expenses on feed consequent upon 'average' mortalities, another consideration is that revenue

Table 56

Expected losses with raceway systems (dry diet: assuming Trouw diet): (Source: Macfarlane, personal communication)

No. of fish at start of period	Mortality over period (%)	Pellet size (Trouw)	Cost of feed over period (£)	Cumulative Feed Cost (£)
10,000	15	00	0.3	0.3
8,500	5	0, 1	21.675	21.975
8,075	2	2, 3, 4	356.8	378.775

is foregone, since the farm is then operating below capacity.

10.3.3 Abnormal losses

Above 'normal losses' may occur for the reasons described previously by Norwegian workers, notably Disease, Systems failures, and Pollution. Lloyds have recently agreed to underwrite the risks of such losses (Macfarlane, personal communication). They are prepared to offer world-wide cover under four categories:

(i) cover against losses due to Viral Haemorrhagic Septicaemia and Infectious Haematopoietic Necrosis.

(ii) cover against losses due to Infectious Pancreatic Necrosis

(iii) cover against losses due to pollution and malicious poisoning

(iv) cover against all other losses if they are incurred within a period of 24 hours.

The total insured risk is of two types:

(A) for category (i): computed as the sum of the disinfection cost and the multiple of annual working cost and cycle time, i.e. the total cost of returning to the position before the loss was incurred.

(B) for categories (ii) - (iv): computed as the assessed net loss, i.e. market value of the actual loss which occurred.

For making decisions upon the premiums applicable in the U.K., 'base rates' exist below or above which a particular farm is rated according to particular conditions. These base rates are: (i) 1%, (ii) 20%, (iii) dependent upon franchise, e.g. 1.6% with a franchise of 10%; 1% with a franchise of 75%. A franchise is the same as an 'Excess clause' in motor insurance, i.e. if the franchise is 75%, claims will only be met where losses comprise 75% or more of the total stock. (iv) dependent upon franchise, e.g. 7% with 10% franchise; 2% with 75% franchise. These rates are applied to the maximum value of stock on the farm at any one time.

The annual cost of insuring stock against various categories of loss may be computed if assumptions are made about the maximum biomass of the stock at any given time and the value of the stock at that time. It is likely under Scottish conditions that one may assume a maximum biomass equivalent to 62.5% of the animal production (i.e. a production ratio of 1:1.6). This may be valued at current dead weights of ca. £650 per ton for market-size fish. However, a more rational valuation would be that based upon restocking prices for live fish (since one may assume that the farmer would wish to restock after a loss). Restocking prices vary with fish length as described, and an average value of £1,000 per ton is assumed in Table 57.

10.4 Power Costs

Power is required for lighting, heating (e.g. office), pumping, processing, freezing, etc., where these operations are performed. It may be provided by electricity, or (less commonly) diesel/fuel oil, or both.

Fish farming has been accepted by the Electricity Board for charging under Farm Tariff, which includes two alternatives:

(a) Standard Tariff:	1,400 primary units	p.a.	@	2.99p.	
	6,800 secondary	"	"	"	1.218p.
	Further	"	"	"	0.756p.

Table 57

Calculation of base-rates (£) for fish farming insurance, at four levels of annual production, assuming maximum value of stock is £1,000/ton liveweight

	Annual production (tons)			
	15	50	100	500
Value of total annual production (£)	15,000	50,000	100,000	500,000
Maximum value of stock at one time (£)	9,375	31,250	62,500	312,500
1% Rate	94	313	627	3,133
1.6% Rate	151	503	1,007	5,033
2% Rate	188	627	1,253	6,267
7% Rate	657	2,190	4,380	21,900
10% Rate	939	3,130	6,260	31,300
20% Rate	1,875	6,250	12,500	62,500

(b) Day/Night Tariff: 1,400 primary units p.a. @ 5.98p.
Further day units (0730 - 2330 hrs.) @ 0.84p.
" night " (2330 - 0730 hrs.) @ 0.357p.

The breakeven point between usage of the two Tariffs is 14,500 units p.a. costing *ca*. £176, for annual consumption rates above which it is cheaper to utilise the Day/Night Tariff.

Power costs for lighting and heating are likely to be insignificant. Power costs for processing and freezing are difficult to ascertain; the latter depends upon the time held in cold store. Average contracted costs for plate freezing are as follows (Morrison, personal communication).

	Cost (pence/stone)
Receive into store	1p.
Freeze and hold for 1 week	5p.
Holding in store per week	1p.

On this basis, it would cost *ca*. £8 per ton to freeze and a further £82 per ton if kept in store for 1 year.

For pumping, power consumption is proportional to the flow rate and to the height pumped. Assuming a 5m. head and that an annual production of 1 ton of trout requires *ca*. 60 g.p.m. waterflow, one may derive from Figure 50 that an annual production of 10 tons would require continuous energy consumption of *ca*. 7.9 kW. Since there will be a linear relationship between water flow and production capacity, it is possible to calculate annual costs for pumping all water to achieve various levels of production capacity (Table 58). These costs would be modified under different circumstances of height pumped and if tariff rates increase, etc.

FIGURE 50

Relationship between advertised water flow rate capability and power rating for centrifugal pumps at two different heads, commercially available in the U.K.

Y = Water flow rate capability (g.p.m.)

X = Power rating (kW)

Sample A (16 pumps) pumping head = 16'

$Y = 82.75 X + 222.53$

$r = 0.80$ $p < 0.001$

Sample B (17 pumps) pumping head = 32'

$Y = 70.10 X + 89.87$

$r = 0.93$ $p < 0.001$

FIGURE 50

Relationship between advertised water flow rate capability and power rating for centrifugal pumps at two different heads, commercially available in the U.K.

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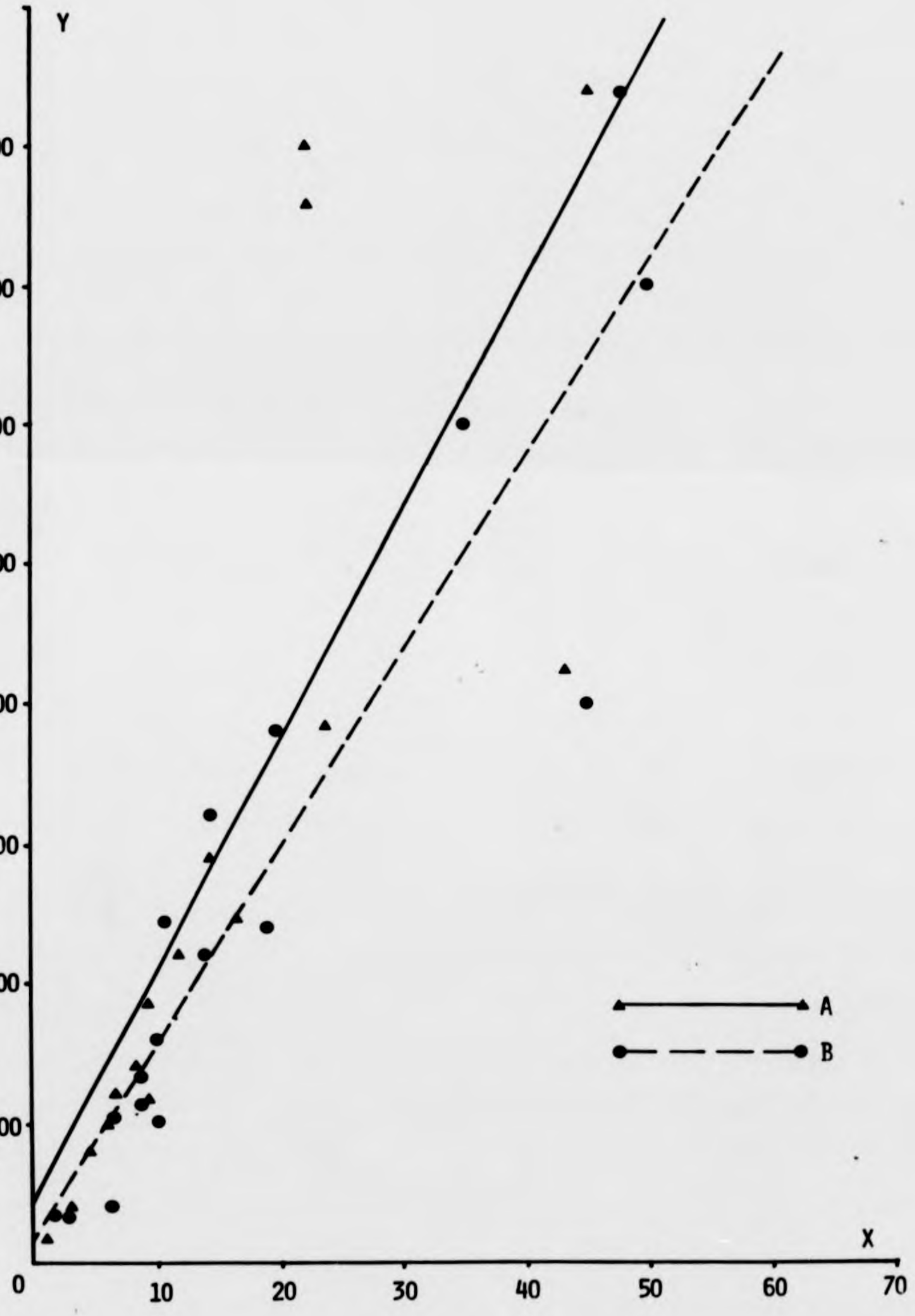

Y
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
10
20
30
40
50
60
70
X
A
B

Table 58

Annual power consumption and costs for pumping all water at a 5m. head (Day and Night Tariff)

Annual Production Capacity (tons)	Required water flow (g.p.m.)	Required power rating (kW)	Annual power consumption (kW Hrs. x 10^3)	Annual cost for electricity (£)
15	900	11.8	103	800
50	3,000	39.4	345	2,400
100	6,000	79.0	690	4,800
500	30,000	394.9	3,451	23,800

10.5 Selling Costs

Selling costs include costs of packaging and transportation and administrative sales expenses (e.g. agency fees and commissions as appropriate).

Fresh trout are usually sold on ice in polystyrene boxes (in half stone and one stone sizes). Half stone boxes retail at 7.7p., i.e. ca. £25 per ton, and are often not returned (particularly from wholesale markets); one stone boxes retail at 9.4p., i.e. ca. £15 per ton.

Home-produced trout in the U.K. is usually transported to the purchaser by road or rail transport. Bulk transport incurs a significantly lower unit cost. Rail freight in the U.K. of a one ton load for a journey of 250 miles would cost ca. 0.6p./lb (i.e. ca. £13 per ton) and loads of less than one ton would have a higher unit cost for transport.

Thus, for example, a trout farm in mid-Scotland wishing to sell one ton of fresh trout per week at Manchester and sending the product in half stone boxes by rail would incur selling costs (excl. agencies) of ca. £2,000 per annum (1.7p. per lb; £39 per ton). A farm in Eire (40 miles from Dublin) which sent 70 tons of fresh trout per annum to Billingsgate by Road, Ship and Rail freight incurred selling costs of £55/ton (incl. agency fees, etc.). This is the order of cost to be anticipated by a farm in Scotland (100 miles from Prestwick airport) whose capacity is being built up to ca. 200 tons per annum, which will be sending fortnightly air-shipments of 8 tons of frozen trout to Montreal. Larger farms would be likely to gain economies of scale, particularly in transport costs. Smaller farms would probably make local deliveries by van or truck.

10.6 Maintenance Costs

Costs of repair and maintenance are likely to reflect the husbandry system in use. Fabricated systems have a far longer life and require less maintenance than earth ponds. Earth raceways and particularly netted systems deteriorate rapidly and require relatively high maintenance costs as does most plant and machinery (e.g. pumps).

Annual farm costs for upkeep (repair and maintenance) may be assumed to be proportional to the sum of the annual depreciation provisions for the various components of total capital costs. The proportion will be assumed to be 20% (Macfarlane, personal communication), although it is likely that small farms constructed cheaply might require higher costs.

10.7 Ova supply costs

Annual costs for ova may be calculated (Table 59) assuming 80% survival at current costs for disease-certified eyed ova of £1.50 per 1,000. If broodstock are reared, ova supplies will be necessary only for the first two years.

10.8 Administration and miscellaneous costs

Annual costs for administration include Travel expenses, Rates, Audit fees, Telephone, Postage, etc. and are likely to comprise both fixed and variable costs. Table 60 shows aggregated values for these costs from four different trout farms (three in Scotland, one in Ireland), given as unit costs and also as a percentage of annual operating costs. These costs may be compared with predicted miscellaneous costs (Macfarlane, personal communication) for raceway farms at

Table 59

Annual costs for bought-in ova supplies for various annual productions of portion-size fish

Annual production of portion-size fish (tons)	10	50	100	500
Annual production of fish (x 10^3)	44.8	224	448	2,240
Annual requirement for ova with 80% survival (x 10^3)	56	280	560	2,800
Annual cost for ova (@ £1.50 per 1,000)	84	420	840	4,200
Approx. annual cost for ova, incl. agency, freight (£)	100	450	900	4,300

Table 60

'Miscellaneous' operating costs (incl. administration) of four Trout farms in the U.K. and Ireland

System	Earth ponds	Earth ponds (and pumps)	Earth ponds	Brick raceways (and pumps and processing)
Annual production capacity (tons)	15	70	70	150
Cost as a %age of total annual operating costs	8	13	9	7
Cost in £/ton production	27	57	36	33

Table 61

'Miscellaneous' operating costs (incl. administration) for a raceway system at four levels of production capacity (after Macfarlane, personal communication)

Annual production capacity (tons)	50	100	200	500
Costs as a percentage of total annual operating costs	7	6	5	4
Cost in £/ton production	25	21	18	11

four different levels of production (Table 61). Macfarlane's suggested scale-economy seems intuitively probable, although not obviously borne out by the historical values given. It might be concluded that these miscellaneous costs are likely to show considerable variation depending upon a farm's individual circumstances and could be in the approximate range of 5 - 15% of annual operating costs. A consideration which will influence the magnitude of such costs in the future is whether fish farms are rated at the lower agricultural rate, instead of the current industrial rating.

10.9 Conclusions: Aggregation of operating costs

The various components of operating cost may be aggregated to provide ranges of total operating cost likely to be encountered, excluding depreciation provisions. A matrix of these ranges at four different levels of production is presented (Table 62), which incorporates feed costs previously considered. A value for the 'most likely' cost of each element is given with the ranges of each cost; such single values obviously assume that the 'most likely' operating costs at a given production level are not influenced by the husbandry system. This is not necessarily the case, however, and variations do occur (e.g. due to automation) and are embraced by the ranges of cost given; such variations are brought out in the case studies (see under 'Financial Assessment').

It may be concluded that feed costs comprise by far the largest component of operating costs (excl. depreciation).

Table 62

Aggregation of annual operating costs (excl. depreciation) at four levels of production (£)

Cost element	Level of annual production (tons)			
	15	50	100	500
1. Feed				
1.1 @ £120 - £300/ton liveweight gain	1,800-4,500	6,000-15,000	12,000-30,000	60,000-150,000
1.2 @ £260/ton liveweight gain	3,900	13,000	26,000	130,000
1.3 = 1.2 as % of total cost	40.5	45.7	47.5	50.3
2. Labour				
2.1 @ £1,500 - £2,500/head	1,500-2,500	3,000-7,500	4,500-12,500	15,000-42,500
2.2 @ £2,000/head	2,000	4,000	6,000	20,000(NP)-34,000(P)
2.3 = 2.2 as % of total cost	20.8	14.1	11.0	7.7(NP): 12.4(P)
3. Insurance				
3.1 @ 0-20% rate	0-1,875	0-6,250	0-12,500	0-62,500
3.2 @ 10% rate	900	3,100	6,300	31,300
3.3 = 3.2 as % of total cost	9.3	10.9	11.5	12.1
4. Power				
4.1 (Upper limit includes pumping all water)	0-1,000	0-2,500	0-5,000	0-24,000
4.2 = 4.1 (upper limit) as % of total cost	10.4	8.8	9.1	9.3
5. Ova				
5.1 @ £1.50/1000	100	450	900	4,300
5.2 = 5.1 as % of total cost	1.0	1.6	1.6	1.7

Table 62 (continued)

Cost element	Level of annual production (tons)			
	15	50	100	500
6. Selling				
6.1 @ £30 - £60/ton	450-900	1,500-3,000	3,000-6,000	15,000-25,000
7. Maintenance				
7.1 = 20% of depreciation p.a. of range of systems	15-156	50-520	100-1,040	500-5,200
7.2 = mean of range of 7.1 (± 49)	100	300	600	2,900
7.3 = 7.2 as % of total costs	1.0	1.1	1.1	1.1
8. Administration and Miscellaneous				
8.1 = 5-15% of total costs	193-1,947	550-6,215	1,025-11,989	4,740-52,235
8.2 = 10% of total costs	963	2,844	5,478	25,833
8.3 = 8.2 as % of total costs	10.0	10.0	10.0	10.0
Total Operating Costs.				
1. Aggregated ranges	5,220-12,978	14,540-41,435	27,502-79,929	133,614-342,353
2. Aggregation of 'most likely' values	9,639	28,444	54,778	258.333

N.B. (P) = incl. Processing; (NP) = excl. Processing; all values are (NP) unless otherwise stated.
Total aggregated range (P) = £148,351 - £358,824;
Aggregation of 'most likely' costs (P) = £273,889.

There is a slight economy in operating costs with increased production, due mainly to labour economies.

CHAPTER II

FINANCIAL ASSESSMENT AND DECISION ASPECTS

11.1 Introduction

It is of interest to compare costs and revenues for trout farms operating under different conditions in order to evaluate profitability. Foregoing data is sufficient to provide general information on likely ranges of trading profit, which might then be related to likely ranges of capital investment. A more specific appraisal of trout farming as an investment may be obtained by examining the discounted earnings of specific trout farming situations as these are modified by various factors.

11.2 Trading Profits

The preceding analysis of operating costs at different levels of production (Table 62) may be summated with corresponding revenues, at various alternative prices, to provide a matrix of upper and lower limits and most likely values for trading profit under these different circumstances (Table 63). Comparison of trading profits with upper and lower limits to possible ranges of total capital cost (Table 64), derived from Tables 45/8) provides a simplified summary of the financial returns to trout farming under various conditions (Table 65-68). It will be observed that positive trading profits occur at all the various price levels considered for the lower limits of production cost. Trading losses occur, however, at some of the price levels considered for the most likely values of production cost and especially for the upper limits of production cost. For the latter, the breakeven sales price

Table 63

Annual trading profit for four levels of production capacity, at three levels of operating cost and five different sales prices (£ x $10^3 \pm 0.4$)

Sales price (£/ton)		500	600	700	800	900
Annual revenue if production = 15 tons p.a.		7.5	9.0	10.5	12.0	13.5
Cost l =	5.0	2.5	4.0	5.5	7.0	8.5
Cost a =	9.0	-1.5	0	1.5	3.0	4.5
Cost u =	13.0	-5.5	-4.0	-2.5	-1.0	0.5
Annual revenue if production = 50 tons p.a.		25.0	30.0	35.0	40.0	45.0
Cost l =	14.5	10.5	15.5	20.5	25.5	30.5
Cost a =	26.5	-1.5	3.5	8.5	13.5	18.5
Cost u =	41.5	-16.5	-11.5	-6.5	-1.5	3.5
Annual revenue if production = 100 tons p.a.		50.0	60.0	70.0	80.0	90.0
Cost l =	27.5	22.5	32.5	42.5	52.5	62.5
Cost a =	51.0	-1.0	9.0	19.0	29.0	39.0
Cost u =	80.0	-30.0	-20.0	-10.0	0	10.0
Annual revenue if production = 500 tons p.a.		250.0	300.0	350.0	400.0	450.0
Cost l =	133.5	116.5	166.5	216.5	266.5	316.5
Cost a =	241.0	9.0	59.0	109.0	159.0	209.0
Cost u =	342.5	-92.5	-42.5	7.5	57.5	107.5

N.B. Cost l, Cost a, and Cost u represent lower limit, commonest value and upper limit of operating cost respectively. (Cost a excludes pumping costs).

Table 64

Lower and upper values for the range of total capital costs predicted for different systems at four levels of production capacity (£)

System		Annual production capacity (tons)			
		15	50	100	500
Earth ponds & raceways					
	Cl	6,000	14,000	28,000	120,000
	Cu	11,000	24,000	44,000	177,000
Fabricated raceways					
	Cl	9,000	26,000	52,000	241,000
	Cu	17,000	42,000	80,000	358,000
Lined earth ponds					
	Cl	6,000	17,000	32,000	142,000
	Cu	13,000	30,000	56,000	237,000
Circular tanks					
	Cl	7,000	20,000	39,000	175,000
	Cu	19,000	50,000	96,000	437,000
Floating systems					
	Cl	4,000	8,000	15,000	61,000
	Cu	9,000	15,000	26,000	95,000
Enclosures					
	Cl	6,000	10,000	20,000	80,000
	Cu	9,000	14,000	25,000	87,000

Cl = lower value of cost
Cu = upper value of cost

Table 65

Trading profit as a percentage return on two levels of capital investment, at three levels of operating costs and five different price levels, for various farms with a production capacity of 15 tons p.a.

Sales Price (£/ton)		500	600	700	800	900
Earth ponds & raceways						
R.O.I. of £6,000	Cost l	42	67	92	117	142
	Cost a			25	50	75
	Cost u					9
R.O.I. of £11,000	Cost l	23	37	50	64	78
	Cost a			14	28	41
	Cost u					5
Fabricated raceways						
R.O.I. of £9,000	Cost l	28	45	62	78	95
	Cost a			17	34	50
	Cost u					6
R.O.I. of £17,000	Cost l	15	24	33	42	50
	Cost a			9	18	27
	Cost u					3
Lined earth ponds						
R.O.I. of £6,000	Cost l	42	67	92	117	142
	Cost a			25	50	75
	Cost u					9
R.O.I. of £13,000	Cost l	20	31	43	54	66
	Cost a			12	23	35
	Cost u					4
Circular tanks						
R.O.I. of £7,000	Cost l	36	58	79	100	122
	Cost a			22	43	65
	Cost u					8
R.O.I. of £19,000	Cost l	14	21	29	37	45
	Cost a			8	16	24
	Cost u					3

Table 65 (continued)

Sales Price (£/ton)		500	600	700	800	900
Floating systems						
R.O.I. of £4,000	Cost l	63	100	138	175	213
	Cost a			38	75	113
	Cost u					13
R.O.I. of £9,000	Cost l	28	45	62	78	95
	Cost a			17	34	50
	Cost u					6
Enclosures						
R.O.I. of £6,000	Cost l	42	67	92	117	142
	Cost a			25	50	75
	Cost u					9
R.O.I. of £9,000	Cost l	28	45	62	78	95
	Cost a			17	34	50
	Cost u					6

N.B. (i) R.O.I. = Return on investment (positive).

(ii) Cost l, Cost a and Cost u represent lower limit, commonest value, and upper limit of cost range respectively.

(iii) All missing values indicate negative percentage returns.

(iv) Notes (i), (ii) and (iii) apply to Tables 65-68 inclusive.

Table 66

Trading profit, as a percentage return, on two levels of capital investment, at three levels of operating cost, and five different price levels, for various farms with a production capacity of 50 tons p.a.

Sales Price (£/ton)		500	600	700	800	900
Earth ponds and raceways						
R.O.I. of £14,000	Cost l	75	111	147	183	218
	Cost a		25	61	97	133
	Cost u					25
R.O.I. of £24,000	Cost l	44	65	86	107	127
	Cost a		15	36	57	77
	Cost u					15
Fabricated raceways						
R.O.I. of £26,000	Cost l	41	60	79	98	118
	Cost a		14	33	52	72
	Cost u					14
R.O.I. of £42,000	Cost l	25	37	49	61	73
	Cost a		9	21	33	44
	Cost u					9
Lined earth ponds						
R.O.I. of £17,000	Cost l	62	92	121	150	180
	Cost a		21	50	80	109
	Cost u					21
R.O.I. of £30,000	Cost l	35	52	69	85	102
	Cost a		12	29	45	62
	Cost u					12
Circular tanks						
R.O.I. of £20,000	Cost l	53	78	103	128	153
	Cost a		18	43	68	93
	Cost u					18
R.O.I. of £50,000	Cost l	21	31	41	51	61
	Cost a		7	17	27	37
	Cost u					7

Table 66 (continued)

Sales Price (£/ton)		500	600	700	800	900
Floating systems						
R.O.I. of £8,000	Cost l	132	194	257	319	382
	Cost a		44	107	169	232
	Cost u					44
R.O.I. of £15,000	Cost l	70	104	137	170	204
	Cost a		24	57	90	124
	Cost u					24
Enclosures						
R.O.I. of £10,000	Cost l	105	155	205	255	305
	Cost a		35	85	135	185
	Cost u					35
R.O.I. of £14,000	Cost l	75	111	147	183	218
	Cost a		25	61	97	133
	Cost u					25

Table 67

Trading profit, as a percentage return on two levels of capital investment, at three levels of operating cost, and five different price levels, for various farms with a production capacity of 100 tons p.a.

Sales price (£/ton)		500	600	700	800	900
Earth ponds and raceways						
R.O.I. of £28,000	Cost l	81	116	152	188	224
	Cost a		33	68	104	140
	Cost u					36
R.O.I. of £44,000	Cost l	52	74	97	120	142
	Cost a		21	44	66	89
	Cost u					23
Fabricated raceways						
R.O.I. of £52,000	Cost l	44	63	82	101	121
	Cost a		18	37	56	75
	Cost u					20
R.O.I. of £80,000	Cost l	29	41	54	66	79
	Cost a		12	24	37	49
	Cost u					13
Lined earth ponds						
R.O.I. of £32,000	Cost l	71	102	133	164	196
	Cost a		29	60	91	122
	Cost u					32
R.O.I. of £56,000	Cost l	41	58	76	94	112
	Cost a		16	34	52	70
	Cost u					18
Circular tanks						
R.O.I. of £39,000	Cost l	58	84	109	135	161
	Cost a		23	49	75	100
	Cost u					26
R.O.I. of £96,000	Cost l	24	34	45	55	66
	Cost a		10	20	31	41
	Cost u					11

Table 67(continued)

Sales price (£/ton)		500	600	700	800	900
Floating systems						
R.O.I. of £15,000	Cost l	150	217	284	350	417
	Cost a		60	127	194	260
	Cost u					67
R.O.I. of £26,000	Cost l	87	125	164	202	241
	Cost a		35	73	112	150
	Cost u					39
Enclosures						
R.O.I. of £20,000	Cost l	113	163	213	263	313
	Cost a		45	95	145	195
	Cost u					50
R.O.I. of £25,000	Cost l	90	130	170	210	250
	Cost a		36	76	116	156
	Cost u					40

Table 68

Trading profit, as a percentage return on two levels of capital investment, at three levels of operating cost, and five different price levels, for various farms with a production capacity of 500 tons p.a.

Sales price (£/ton)		500	600	700	800	900
Earth ponds and raceways						
R.O.I. of £120,000	Cost 1	97	139	181	222	264
	Cost a	8	50	91	133	175
	Cost u			7	48	90
R.O.I. of £177,000	Cost 1	66	94	123	151	179
	Cost a	5	34	62	90	118
	Cost u			5	33	61
Fabricated raceways						
R.O.I. of £241,000	Cost 1	49	69	90	111	132
	Cost a	4	25	46	66	87
	Cost u			4	24	45
R.O.I. of £358,000	Cost 1	33	47	61	75	89
	Cost a	3	17	31	45	59
	Cost u			2	16	30
Lined earth ponds						
R.O.I. of £142,000	Cost 1	82	118	153	188	223
	Cost a	7	42	77	112	148
	Cost u			6	41	76
R.O.I. of £237,000	Cost 1	50	71	92	113	134
	Cost a	4	25	46	67	89
	Cost u			4	25	46
Circular tanks						
R.O.I. of £175,000	Cost 1	67	96	124	153	181
	Cost a	6	34	63	91	120
	Cost u			5	33	62
R.O.I. of £437,000	Cost 1	27	39	50	61	73
	Cost a	2	14	25	37	48
	Cost u			2	14	25

Table 68(continued)

Sales price (£/ton)		500	600	700	800	900
Floating systems						
R.O.I. of £61,000	Cost l	191	273	355	437	519
	Cost a	15	97	179	261	343
	Cost u			13	95	177
R.O.I. of £95,000	Cost l	123	176	228	281	334
	Cost a	10	63	115	168	220
	Cost u			8	61	114
Enclosures						
R.O.I. of £80,000	Cost l	146	209	271	334	396
	Cost a	12	74	137	199	262
	Cost u			882	72	262
R.O.I. of £87,000	Cost l	134	192	249	307	364
	Cost a	11	68	126	183	241
	Cost u			9	66	124

is reduced with increased annual production, e.g. the breakeven sales price at 15 tons p.a. production is £800 - £900 per ton, and at 500 tons p.a. production is £600 - £700 per ton, indicating economies of scale. The relationship between trading profit and capital cost (upper and lower limits of range), given as a percentage return on investment, is also highest at 500 tons production, i.e. at a price of £900 per ton, for the lower limit of production cost, the return is ca. 500% when using a floating system (lower limit of capital cost range). In general, this relationship is very sensitive to changes in sales price and it reflects the low ratio of fixed to working capital inherent in trout farming. This is particularly evident for low capital intensive systems, e.g. for the upper limit of capital cost of a 500 ton p.a. floating system (£95,000), the ratio of fixed to working capital requirements is ca.1:2.6 for the most likely value of production cost. The current wholesale price of fresh trout is ca. £650 per ton and if, for a 15 tons p.a. production farm, the 'most likely' value of production cost is incurred (£9,000), a net trading profit of £750 would accrue. Since capital charges have not been considered in this analysis, it may be concluded that trout farms with an annual production not exceeding 15 tons per annum are unlikely to be profitable investments. This is in agreement with the claim of certain trout farmers (e.g. Gordon, personal communication) that, at current price levels, an annual production of 15 tons p.a. approximately represents the breakeven scale of production.

11.3 Model of trout farming evaluation

The foregoing examination of the profitability of trout farming may be extended, and linked with preceding considerations, to provide an overall model which analyses the biological, technical, and economic factors relevant to investment decisions. The model (Fig. 51) may be used to provide a framework for the sequential decisions to be made during evaluation of a site for its trout farming potential.

11.4 The use of case studies

The various criteria involved in decisions relating to trout farming investments may be illustrated by the use of case studies. This approach has several advantages, e.g.

(i) to demonstrate the quantity and quality of information which is usually available to the investor.

(ii) to provide worked examples, using the sequential questions and decision rules previously considered, of the evaluation of a site and investment.

(iii)to examine how the attractiveness of an investment may be modified under different circumstances.

(iv) to consider the overall potential of the Scottish highlands and islands for trout farming developments.

Three case studies are described; these are hypothetical but none of the details of the cases may be regarded as improbable.

CASE STUDY I

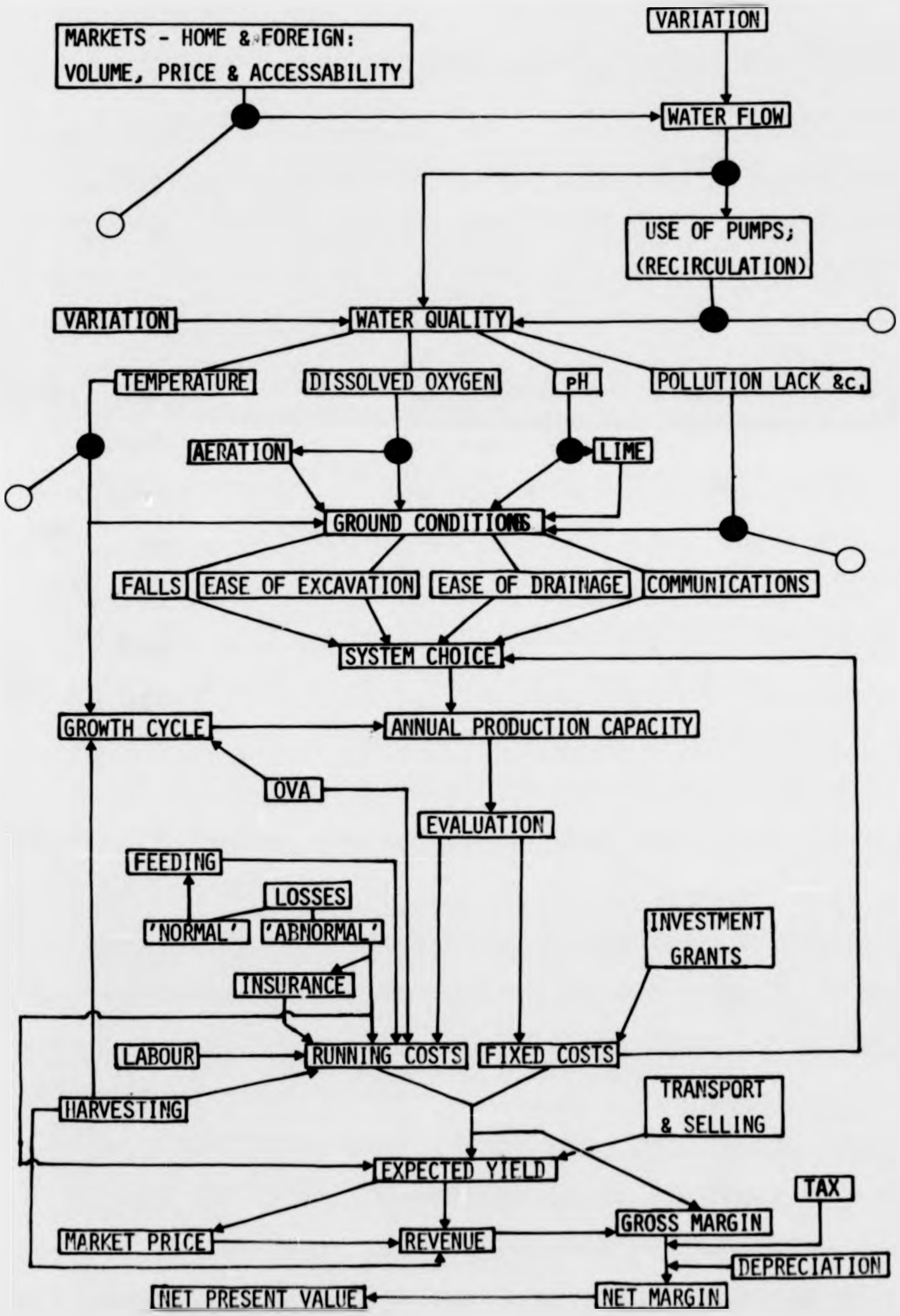
(Legend: Q = question; A = answer)

Q.1. An estate bordering a deep freshwater loch in Inverness-shire wishes to investigate the possibilities of utilising some unproductive land for trout farming. The site under

FIGURE 51

Model of the variables to be considered when making investment decisions relating to trout culture. The model is represented by a flow chart of the sequential decisions which are required.

Major decision nodes are represented by solid circular symbols. 'Stop' decisions to abandon further investigation are represented by hollow circular symbols. It should be noted that, although many of the interdependencies have been indicated (e.g. by feedback loops), this model has not attempted to consider all such relationships and the whole decision process must be regarded as iterative.


MARKETS - HOME & FOREIGN: VOLUME, PRICE & ACCESSABILITY
VARIATION
WATER FLOW
USE OF PUMPS; (RECIRCULATION)
VARIATION
WATER QUALITY
TEMPERATURE
DISSOLVED OXYGEN
pH
POLLUTION LACK &c.
AERATION
LIME
GROUND CONDITIONS
FALLS
EASE OF EXCAVATION
EASE OF DRAINAGE
COMMUNICATIONS
SYSTEM CHOICE
GROWTH CYCLE
ANNUAL PRODUCTION CAPACITY
OVA
EVALUATION
FEEDING
LOSSES
'NORMAL'
'ABNORMAL'
INSURANCE
INVESTMENT GRANTS
LABOUR
RUNNING COSTS
FIXED COSTS
HARVESTING
TRANSPORT & SELLING
EXPECTED YIELD
TAX
MARKET PRICE
REVENUE
GROSS MARGIN
DEPRECIATION
NET PRESENT VALUE
NET MARGIN

consideration borders the loch and is transected by a small river as it enters the loch. It comprises an area of 15 acres and is connected by a forestry road (unmetalled) to the estate office, which is at a distance of one mile, and thereafter by metalled roads to the nearest township, Mallaig, at a distance of 15 miles. Does a market exist for trout farmed here and, if so, what is the likely product-type(s), price, volume, etc. and is the market accessible from the farm?

A.1. A fish wholesale company in London has agreed to pay a minimum price of 2p./lb. less than the first-hand Danish import price C.I.F. Billingsgate for fresh trout, on ice, 'in the round', provided

(i) 240 stone are delivered weekly in polystyrene boxes, the fish being of suitable quality and accurately graded into three weight classes: 5-6 oz., 6-7 oz., 7-9 oz.

(ii) the deliveries commence within a 24 month period from the time of contract and thereafter continue uninterrupted for a further 12 months, before which time the price cannot be subject to renegotiation.

A fish haulage contractor making weekly runs by road from Mallaig to Billingsgate has agreed to carry up to 2 tons per week as required at £30 per ton, if the load is in excess of 1.4 tons per week.

At current first hand prices (ca. 29p./lb.), this contract would permit the farmer a minimum price of 27p./lb., assuming prices did not decline during the year and provided the first year's production was in excess of 78 tons per annum. Delivery charges from Mallaig to London would be ca. £2,300 per annum and revenue would be ca. £47,200 per annum for an annual production of this scale.

Q.2. What is the water availability at the site?

A.2. Comprehensive records of water flow for the river do not exist and wide variations occur. A 10 year-old survey by the Hydroelectric board advised a mean flow rate of ca. 4,000 g.p.m., and stated one recording in late May of 850 g.p.m. Installation of pumping facilities on the lochside would, however, appear to be feasible.

If an 18 month production cycle for portion size fish is assumed and a potential production of 1 ton p.a./60 g.p.m. water flow, then the potential productions based on 4,000 g.p.m. and 850 g.p.m. would be 67 and 14 tons p.a. respectively. It is likely that a constant supply of 4,000 g.p.m. would be insufficient to achieve the minimum price contract, and a constant supply of 850 g.p.m. would be insufficient for the farm to break-even (if selling F.O.B. farm at the same price). Provision of a water supply adequate for an annual production of 78 tons would probably require ca. 4,700 g.p.m., or more should the cycle time be in excess of 18 months. This would entail installation of pumping facilities from the loch, with the option of supplementing from the river supply, should this be practicable. Data supplied hitherto would indicate that pumping investments may be economical at a production capacity of 78 tons p.a. There would appear to be sufficient evidence of possibilities for trout farming at this site, when considered together with four other factors -

1) high unemployment and the availability of local labour, e.g. from Mallaig port.

ii) the existence of road and rail transport to Mallaig, e.g. for feed supplies.

iii) the absence of any industrial activity on the watershed under examination, i.e. lack of possible pollution.

iv) possibility of H.I.D.B. assistance. - to indicate the advisability of a technical appraisal at the site.

Q.3. Following the technical appraisal, what factors of water quality and ground conditions were found to exist relevant to the feasibility of trout farming at the site?

A.3.1. Water temperature.

The annual temperature range was estimated from (i) actual recordings, (ii) comparative studies existing for similar systems, (iii) consideration of the altitude of both the site (*ca* 200' above sea level) and the total watershed, and from the effect of the distance from the coast (5 miles) and the prevailing climatic characteristics etc. The range was estimated at 2°C - 17°C with an overall mean of *ca*. 9°C.

A.3.2. Other water characteristics.

Dissolved oxygen levels indicated full saturation in the river and surface layers of the loch. pH levels varied between 5.2 and 7.2 in the river mouth, with a mean value of *ca*. 6.6. The fluctuation in pH levels was probably due to the low levels of dissolved salts recorded (i.e. *ca*.10 p.p.m. Calcium). Heavy metal ions were detected only in trace amounts and there was no evidence of any pollution, e.g. sheep dips, or substances likely to prove toxic to fish. The surface of the loch exhibits variation in level over a vertical distance of *ca*.1.5'. Brown trout were resident throughout the river and loch system. Migratory salmonids also occurred but were unable to negotiate the waterfalls which exist at a distance of ½ mile upriver from the loch.

A.3.3. Ground conditions

The land bordering the river mouth and lochside is composed of a 2' depth of peat/top-soil, overlying igneous rock strata. The shore rises to 2' vertically above the upper limit of the loch surface at a horizontal distance of 6' from the shore; thereafter, there is a slight gradient until at a horizontal distance of ca. 6,000' from the lochside a vertical escarpment occurs. The river bed is ca. 30' wide at the mouth beyond which it falls away sharply into the loch. The unfenced land on either side has an average gradient down towards the loch of ca. 1/100.

The temperature of the water would indicate a probable growth cycle of ca. 1½ years for Rainbow trout. The poor buffering capacity would suggest that there might be advantages to be gained by addition of Calcium Carbonate to the water to prevent sudden changes in pH, e.g. following spate conditions, causing stress to farmed fish. The erection of a fish barrier at the mouth of the river and the killing-out of wild fish above might reduce the possibilities of disease conditions arising from the natural stocks. The nature of the terrain would exclude the possibilities of using conventional excavated earth ponds for rearing trout. The steep submerged gradient of the loch would reduce the possibilities of using fixed enclosures within the loch. The site would appear to be suited to the use of either raceway and/or circular tanks on the shore, or floating facilities within the loch. Use of the former would require provision of pumping facilities to raise water from the loch in order to supplement the gravity-fed supplies diverted from the river.

Q.4. What is the annual production capacity of the site, and how best might this be exploited technically, if there is a financial constraint of e.g. £100,000 for fixed and first year's working capital (i.e. including total capital investment)?

A.4. The production capacity using floating systems would be limited only by the area of the loch which might be utilised and cost considerations. However, a problem would arise due to lack of control. Grading and harvesting are a particular problem with floating nets and/or cages and the minimum market constraint of 1½ ton per week would discourage the use of such systems. Since it would be necessary to pump in order to satisfy the market requirements for fish from a shore-based facility, production capacity in this case would be limited primarily by the nature of the pumping investment. In order to achieve a steady supply of marketable fish throughout the year, it would be necessary to have fish hatching during the summer, i.e. supplementing the natural winter hatch with imported eggs. The tendency for shortfalls in supply of marketable fish would be reduced with an increase in production capacity above the minimum market sales volume, due to the consequent added flexibility for differential feeding rates, etc. Thus, it is likely that the choice of annual production capacity would be in excess of 78 tons, and at a production level which permitted economies of scale (particularly for labour), while satisfying the maximum cost constraint. Assuming that diseconomies would not arise (particularly for marketing), cost evaluation would seek to discover the level of annual production which permitted maximum scale economy within the cost constraint. This could be at a production of e.g. 100 tons per annum, but evaluation is likely to comprise an iterative procedure as each search provides further information for subsequent searches.

Q.5. What are the likely costs and profit potentials of both raceway and circular tank trout farms producing approximately 100 tons per annum at this rate?

A.5. The ranges of total capital costs likely for fabricated raceway and circular tank systems at a production capacity of 100 tons per annum may be predicted as £70,000 - £107,000 and £57,000 - £123,000 respectively (excluding processing; including pumping investments). The range of operating costs at this scale of production may be predicted as £28,000 - £80,000, with a current 'likely value' of ca. £55,000 (excluding depreciation provisions; including pumping costs for all water up a 16' head and assuming feed costs at £260 per ton liveweight gain, insurance at 10%, total labour costs of £6,000 per annum etc., as in previous analyses). Thus it is likely that the minimum cost constraint would be exceeded at this scale of annual production.

A 10% reduction in planned production capacity (i.e. 90 tons per annum) would have a most likely annual operating cost of ca. £50,000. The revised capital cost structure for circular tanks would have a lower limit of the same order, i.e. using 30' diameter tanks constructed from preformed silo staves. The annual trading profit may be calculated in this case:

Minimum annual revenue @ 27p./lb for 90 tons production = ca. £54,400

Operating costs:

(i) Feed @ £260/ton liveweight gain = £23,400
(ii) Labour costs = £6,000
(iii) Selling costs = £2,700
(iv) Power (pumping ca. ½ water requirement) = £3,000
(v) Maintenance and ova = £1,500
(vi) Miscellaneous (incl. insurance @ 10%) = £10,000
Total operating costs = £46,600

Gross trading margin = ca. £8,000
= Return on fixed investment(£50,000) of 16%.

Q.6 What is the net present value of this investment when discounted at different rates of return, and how is it altered by changes in sales price, feed cost and capital cost?

A.6 The following assumptions will be made:

(i) The farm operates substantially over a period of 10 years, designated years 1 - 10.

(ii) During year 0, the farm is constructed, commencing with the hatchery, which is first stocked with eyed eggs in February. The resulting fry are reared to become fingerlings by the end of year 0, and are first marketed as ½ lb. fish in July of Year 1.

(iii) During year 11, the only cash flows are tax outflows based on the profits of year 10. Corporation tax is charged at a rate of 42.5% and is paid one year in arrears.

(iv) The cash flows in year 0 are all negative, and comprise fixed capital investments and some working capital. The former is composed of buildings and construction and of processing and pumping machinery. The latter is composed of the operating costs incurred in rearing fish resulting from the eggs first introduced to the farm in February; this is computed as 20% of the annual operating costs incurred when the farm is fully on-line (i.e. after July of year 1).

(v) The cash flows in year 1 include positive and negative flows. The positive flows represent revenue which first starts to accrue in July and thereafter continuously; the total revenue accruing in year 1 is half of that in year 2; this is because a steady state is not achieved until July of year 1, after which the farm is maintained to produce its maximum annual capacity until year 10 (inclusive).

(vi) Investments in buildings and construction are completed by the end of year 0, after which they are depreciated over 10 years by the straight-line method. Investments in processing and pumping machinery are completed by the end of year 0, after which they are depreciated over a period of 3 years by the declining balance method; new investments are made in years 4 and 7, at the end of their economic life, and appear as negative cash flows in those years. Zero scrap-value is assumed for all investments.

(vii)The cash flows in years 2 to 10 comprise the positive and negative flows associated with the revenues and operating costs respectively due to the annual production of 90 tons of trout. In certain cases, negative flows occur in years 4 and 7 due to new investments; these (see (vi)), and all other cash flows are assumed to accrue at the end of the year.

The discounted cash flow calculations were largely performed using a computer program in Fortran IV, written by S. Jones ('net present value 72'). A sample input file and output data are given in Appendix V

The net present value (N.P.V.) of this investment when the costs and earnings of the project are discounted at a 10% rate of return is - £28,000. The discounting procedure thus makes this investment appear unattractive compared with the value of its undiscounted percentage return on capital employed (16%). This is largely due to the greater consideration given to the cash flows in the early years than to those in later years. The fact that the farm is not working at capacity until year 2 and the explicit consideration of the cost of new capital investments in years 4 and 7, make the project appear less attractive when discounted.

The influence on the N.P.V. of various alternative assumptions is considered (Table 69). It may be concluded that only in the event of a 30% increase in sales price, with costs remaining constant, is the project likely to appear attractive when discounted in this manner, in which case the solution rate of return would be ca. 20%.

Table 69

N.P.V. of Case 1 under 10 different conditions

Assumption	N.P.V.($\pounds \times 10^3$) (@ 10% rate of return, unless otherwise stated)
1. 30% increase in sales price(to 35p/lb.)	30
2. 30% increase in sales price; 20% rate of return	1
3. 30% increase in feed cost & in sales price	4
4. 50% decrease in capital cost (buildings and construction)	-11
5. 20% decrease in capital cost (buildings and construction)	-21
6. 50% taxable grant for buildings and construction in year 1	-12
7. 20% taxable grant for buildings and construction in year 1	-21
8. 50% taxable grant for fixed and first year working capital in year 1	1
9. 20% taxable grant for fixed and first year working capital in year 1	-16
10. 100% depreciation of building and construction in year 1	-10

CASE STUDY II

Q.1. The farmer in Case I has been advised that a very large trout farm, which produces 500 tons p.a. might permit certain economies. In addition, the previous cost constraint has been removed and he has decided to use raceways rather than circular tanks because of certain operating advantages. What would be the minimum capital cost at this site?

A.1. Apart from individual characteristics of the site topography, this would be influenced by the necessity to pump water and by the anticipated cycle time (18 months) and harvesting pattern. A holding : production capacity (production ratio) of 1 : 1.6 may be assumed from biological data already obtained, and it is anticipated that a minimum of 6 tons would be marketed per week (average of 9.6 tons per week). This would entail provision of facilities for holding ca. 350 tons of marketable fish at any one time. There would be a requirement for facilities to pump ca. 30,000 g.p.m. If sited on the land perpendicular to the shoreline, raceways could be constructed with minimal excavation because of the suitability of the ground and gradient. Brick raceways have a lower cost than concrete or fibreglass, and probable outlays for this and other items of fixed capital investment are estimated as follows:

(i) Hatchery and early-rearing (concrete fry tanks, automatic feeding for fish up to a length of 3")............. £14,000

(ii) Land (zero opportunity cost in this case) 0

(iii) Miscellaneous: Vehicles - £8,000 (truck, tractor, feeder truck and dumper); Roads - £2,000 (7,500' @ 80p./linear yard);

Boundary fence and lights - £3,000; Others - £2,000.... £15,000

(iv) Pipelines - £6,000 (1,500' of 8" and 12" diam. plastic piping); Water channels - £15,000 (1,500' inflow channel and supplementation channel from river; 500' outflow channel @ £7/sq. yd. for wall and @ £3/sq. yd. for bases); Dams for river - £4,000 .... £25,000

(v) Buildings

a) 1110' x 15' @ £3.50/sq. ft. - £5,575 for processing

b) 60' x 20' @ £4/sq. ft. - as feed store and office adjoining - £6,425 .... £12,000

(vi) Pumps and pumphouse. Pumps: 5 pumps; priming equipment, generator, other electrical equipment - £20,000; Pumphouse and excavation to deliver a 15' head utilising an inlet pipe on a floating pontoon - £15,000 (some blasting required) £35,000

(vii) Raceways (brick and concrete bases) and initial excavation and levelling £150,000

(viii)Contingencies (including cost inflation between estimate and all contracts) @ 10% .... <u>£25,000</u>

Total capital cost = <u>£276,000</u>

Q.2. What are the operating costs and revenues with two alternative assumptions (a) selling fresh 'in the round' at Billingsgate, at the price the market would bear; (b) selling to Clouston's of Montreal, Canada: gutted and gilled frozen trout @ 40p./lb. F.O.B. Montreal if transport costs from farm to port of delivery using road and air freight for weekly deliveries of 9.6 tons are £56,000 per annum?

A.2. (i) Annual Operating costs:

	Selling frozen Cost (£)	Selling fresh 'in the round' Cost (£)	
1. Feed	130,000	£130,000	
2. Labour	25,000	20,000	
3. Insurance	31,300	31,300	
4. Power	28,000	24,000	
5. Ova	4,300	4,300	
6. Selling (@ £112/ton)	56,000	10,000	(@ £20/ton)
7. Maintenance	4,000	2,900	
8. Miscellaneous	22,300	22,300	
	£300,900	£244,800	

(ii) The capital costs for gutting and freezing would be £18,000 - £26,500 depending upon the method of freezing. The total incremental capital cost (including capacity to hold 10 tons in cold store) would probably be ca. £30,000, depreciated over 3 years.

(iii) The revenue accruing from sales of fresh trout at prices of 25 and 29p./lb. are £280,000 and £325,000 respectively (giving consequent values for G.T.M.* of £35,000 and £80,000 respectively). Frozen trout production involves processing and consequent weight loss of ca. 20% of the product. Assuming there is no market for trout viscera, the revenue accruing from sales of frozen trout at prices of 30 and 40p./lb. are £323,000 and £358,000 (giving consequent values for G.T.M.* of £22,000 and £58,000 respectively).

These four options all give a negative N.P.V. when discounted at 10%, as follows:

* Gross Trading Margin

i) Fresh trout @ 29p./lb.; N.P.V. = -£16,000

ii) Fresh trout @ 27p./lb.; N.P.V. = -£106,000

iii) Frozen " @ 40p./lb.; N.P.V. = -£146,000

iv) Frozen " @ 36p./lb.; N.P.V. = -£304,000

Thus, it is not apparent that there are significant economies of scale in this case when compared with an alternative smaller investment at the same site. However, the larger annual production might allow the farm a greater ability to influence the market and thus obtain higher prices than in Case I.

Q.3 What would be the comparative cost/effectiveness of purchasing second-hand fishing boats in order to obtain trash fish as an alternative feed to bought-in dry pellets?

A.3. At current prices and likely conversion rates, the feed cost for the production of £500 tons per annum using bought-in pellets is <u>ca</u>. £130,000. The same annual production would require <u>ca</u>. 3,000 tons of trash fish which would probably require four x 55' fishing boats. There would be incremental capital and running costs, notably for freezing, cold store, mincing and transport. The various capital costs are summarised below:-

A. Fresh trout production - Capital costs

i) 10 year economic life - £352,000, made up as farm costs (£256,000) + boats (£90,000) + mincing and cold store (£6,000).

ii) 3 year economic life - £92,000, made up as:- fishing nets (£72,000) + pumps (£20,000).

B. Frozen trout production - Capital costs

i) 10 year economic life - £349,000, made up as:-

farm costs (£256,000) + boats (£90,000) + mincing (£3,000)
ii) 3 year economic life - £122,000, made up as:-
fishing nets (£72,000) + processing and cold store (£30,000) + pumps (£20,000)

Incremental annual operating costs would comprise wages (£7,500) and transport (£5,000) giving total annual operating costs for fresh and frozen trout production of £127,000 and £183,000 respectively.

Using the prior assumptions, the consequent cash flows may be discounted to evaluate investments using wet feed trawled for by the trout farm vessels (Table 70). These are obviously more profitable investments than those using dry bought-in diets at current price levels.

Although a comparison of the probable differential prices for frozen and fresh trout (36 - 40p./lb.; ca. 29p./lb.) would favour the production of the latter, the ability of the farmer producing frozen trout to perform the following:-

i) hold it in store until prices are favourable.
ii) transport product to markets at a greater distance than would ordinarily be possible for fresh trout.
iii) exploit a world market for frozen trout which is potentially larger and increasing more rapidly than (and possibly at the expense of) fresh trout;-

should be considered important factors in making the choice between frozen and fresh trout sales.

Table 70

N.P.V. of a 500 ton production trout farm using trash fish (Self-caught) under six different conditions

Product (trout)	Selling Price (p./lb.)	N.P.V. rate of return (%)	N.P.V. (£ x 10^3)
fresh	29	10	289
fresh	29	20	48
fresh	29	30	-89
frozen	40	10	156
frozen	40	20	-67
frozen	36	10	24

CASE STUDY III

Q.1. Since trout farms operate profitably in other parts of the U.K., Ireland and Scandinavia with annual productions of 15 - 30 tons per annum, as 'family concerns', would there be a possibility for similar farms in the West Highlands and Islands of Scotland?

A.1. Such farms in the U.K. and Ireland are usually for restocking, but certain earth pond systems exist profitably for production of table fish, and certain marine systems are operated similarly in Norway. These small table farms may be an adjunct to various other enterprises (mostly agricultural or fishing), and either sell their produce locally, or to a larger farm (e.g. in Ireland), or to a co-operative sales organization (in Norway and Denmark). The choice of sites suitable for earth pond systems in this area of Scotland is very limited. There are many coastal sites very suitable for marine culture, e.g. using floating nets. However, unlike Norway, a market does not currantly exist for large trout (ca.2 lbs.), and marine culture of small trout (6 - 8 oz.) is difficult technically and economically. It is likely that the natural resources of the area are most suited at low levels of production to utilisation of either floating nets/enclosures in fresh water (e.g. fresh water lochs) or cheap circular tanks (e.g. with preformed silo staves).

Q.2. What are the likely costs and profit potentials of low production fresh water systems using floating nets/enclosures and/or low cost circular tanks?

A.2. The ranges of total capital cost for farms with a production capacity of 15 tons per annum are as follows:

(i) Circular tanks - £7,000 - £19,000
(ii) Floating systems - £4,000 - £9,000
(iii) Enclosures - £6,000 - £9,000

Operating costs (excluding depreciation) are likely to be within the range £5,000 - £13,000 with a probable value of ca. £9,000. At a sales price of £650/ton, annual revenue would be £9,750, i.e. a gross trading margin of £750. It is possible for one man working alone to produce up to 30 tons per annum, although 25 tons may be considered a more usual maximum. An annual production of 25 tons would permit more efficient resource allocation. There would be certain capital cost economies, e.g. vehicle, hatchery, although the cost of holding facilities would probably be increased pro rata, and an increment of 50% over the capital cost at 15 tons capacity may reasonably be assumed - giving capital costs for a production capacity of 25 tons per annum for

(i) Circular tanks = £10,500 - £28,500
(ii) Floating systems = £6,000 - £13,500
(iii) Enclosures = £9,000 - £13,500

Operating cost economies would comprise labour and selling costs, giving annual operating costs with a probable value of ca. £14,000, for a corresponding annual revenue @ 29p./lb. of £16,250. The gross trading margin at an annual production of 25 tons (ca. £2,250) would generally cover fixed charges for depreciation (£1,000 - £3,000 per annum, depending on the system used and depreciation period assumed.)

Discounting the costs and earnings of such a farm gives a less attractive appraisal of the investment. Selling at

29p. per lb., the N.P.V. would be - £6,000 at a 10% rate of return. The apparent profitability of certain small farms is possibly due to various costs being 'hidden' or undercharged, particularly labour and capital costs.

Q.3. Is the risk element likely to deter small investors?

A.3. The very substantial risks involved in trout farming are increasingly being covered by the purchase of insurance. However, this is likely to be too costly for small farms, and the choice of cover has a considerable influence on the annual costs and the N.P.V. of the farm (Table 71).

Table 71

Effect of cost of three different categories of insurance cover on N.P.V. of a 25 ton per annum production trout farm

Cover	Rating (%)	Annual Cost (£)	N.P.V. (£ x 10^3) Discounted at 10%
1. Pollution and/or malicious fish kills	1	150	-0
2. Certain diseases and fish kills	10	1,500	-6
3. All diseases, fish kills, etc.	20	3,100	-13

It could be that bodies with a promotional involvement in trout farming, e.g. the H.I.D.B., would be better advised to protect their investments by contributing to the cost of insuring such farms than providing unallocated finance. Thus, in this case, a taxable grant of 50% of the total initial capital cost (£3,000) would raise the N.P.V. of the farm from - £6,000 to - £3,000 without necessarily altering the high element of risk. A similar grant to be used entirely for insurance cover would help to ensure that the N.P.V. did not decline below - £6,000, of which there would otherwise be a high probability. Apparently at the present time the risk element seems unlikely to deter small investors. However, it is already proving a major deterrent to large investors in this field, and is likely to prove an increasing deterrent to further promotional involvement by governmental agencies of small (and large) investors. Where such involvement has an objective of increasing employment opportunities, it could be of particular concern that new employment is sustained, possibly at the expense of financial solvency under certain circumstances.

Q.4. How, if at all, could the existence of a central marketing co-operative benefit such farms?

A.4. The population density and availability of wild salmonids in the Highlands and Islands area limits the potential market for farmed salmonids in that region. Furthermore, communications are often difficult and it is likely that there would be severe marketing problems for trout farms with small annual productions, which would probably sell direct to local hotels, etc. In this region, such hotels would prefer regular supplies of fresh trout, but these supplies would entail a high unit selling cost to farmers with a low scale production. Such a situation occurs in Norway where a co-operative sales organisation has emerged in an attempt to assist small farmers with marketing problems sited at a distance from the main centres of communication. The main advantage to the farmer would appear to be:

i) the ability of the co-operative to purchase capital equipment notably for processing, freezing and holding in cold store.

ii) the consequent ability to build up and hold fish stocks from various farm sources, which may then be released on to the market at the most favourable time for the farmers, i.e. the co-operative thus acting as a major producer and the members being then able collectively to obtain favourable markets in competition with other major producers.

iii) A central organisation of this nature could also serve the members, e.g. by acting as a central feed source, by providing disease diagnostic services, etc. This is not practised in Norway, but both of these services are available on a co-operative basis in Denmark.

CHAPTER 12

SUMMARY AND CONCLUSIONS

Rainbow trout is the only species whose intensive culture for human consumption has already proved commercially viable in Scotland. However, the culture of certain other species, notably Atlantic salmon and Oysters is likely to be profitable, and would represent more rational exploitation of the natural resources available on the Scottish west coast.

Consideration was given to the various factors involved in decisions relating to investment in trout farming at the present time. Comprehensive appraisal should take account of the constraints imposed by market, site, technological, capital and operating cost parameters.

It would appear that current costs and revenues are such as to make trout farming in Scotland an unattractive investment after discounting. This is particularly so when the risks associated with this industry are considered. Costs are dominated by feed costs which have recently escalated and which are closely related to the cost of seafish products. If there are significant increases in trout prices and/or feed costs are reduced, then investments would become more attractive as profitability is particularly sensitive to changes in revenue and operating costs. Larger farms are unlikely to achieve very significant cost economies but are likely to obtain market advantages with respect to smaller farms. Farms which obtain their own seafish for feed, e.g. by industrial fishing, might be highly profitable.

Future study in this area should benefit from improvements in the quantity and quality of data available. Of particular interest would be more information on the costs and probabilities associated with the various risk elements in trout farming, notably disease, and the cost/effectiveness of insurance cover. An increased understanding of the problems associated with marine culture of trout would be an advantage, particularly if the home market became favourable to the production of larger fish at an enhanced unit value.

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Biology: Professors F G T Holliday
Hans Meidner

APPENDIX I.

NIVERSITY OF STIRLING STIRLING SCOTLAND | TELEPHONE: STIRLING (0786) 3171

Dear Sir,

I would be grateful for any assistance which you can give to Mr. Jonathan Shepherd of this department. He is making a study of the present and future role of fish farming, with particular reference to the West of Scotland, which is intended to clarify the biological and economic factors relevant to different types of fish farming enterprise. The information gained during this work will comprise part of a doctoral thesis. Lest any commercial interests be endangered, the thesis will be written in 2 volumes, one of which will contain any confidential matters. The Secretary of the University, Sir Derek Lang, is prepared to guarantee that the latter volume will not be made available to any person without the prior permission of the fish farmer(s) concerned. It is emphasized that the work will be seen by the two supervisors, Dr, D. S. McLusky and Mr. J. F. Woodward, the external examiner (to be appointed), and myself only. Your co-operation in this study would be much appreciated.

Yours faithfully,

F. G. T. Holliday

Professor F.G.T. Holliday.

APPENDIX II

SYNOPSIS OF VISITS AND INTERVIEWS

I. Scotland

1. Almondbank Salmon Hatchery (D.A.F.S.), by Perth (1)
2. Boots Trout Farm, Brechin, Angus (1)
3. Cantray Trout Farm, Croy, Inverness (3)
4. College Mill Trout Farm, Almondbank, Perth (3)
5. Crook of Devon Trout Farm, Kinross (1)
6. Gateway West Argyll Ltd., Ford, Argyll (6)
7. Highland Trout Co. Ltd., Otter Ferry, Argyll (6)
8. Howietoun and Northern Fisheries Ltd., Bannockburn (10)
9. Howietoun and Northern Fisheries Ltd., Blairgowrie (2)
10. Inverpolly Estates Ltd., by Lochinver, Wester Ross (1)
11. Jas. Johnston & Co. Ltd., Montrose, Angus (1)
12. Kenmure Fisheries Ltd., New Galloway, Kirkcudbrightshire (2)
13. Marine Harvest Ltd., Loch Ailort, Inverness-shire (1)
14. Pitlochry Salmon Hatchery (D.A.F.S.), Faskally, Perthshire (2)
15. Rosscairn Fisheries Ltd., by Buckie, Morayshire (1)
16. West of Scotland Trout Farms Ltd., Bridge of Weir, Renfrewshire (1)

II. England, Wales and Northern Ireland

1. Avon River Fisheries Ltd., Fordingbridge, Hants (1)
2. Bayfield Trout Farms Ltd., Glandford, Holt, Norfolk (1)
3. Cooper's Experimental Trout Farm, Haningfield, Reservoir, via Colchester, Essex (1)
4. Lincolnshire Trout Farms Ltd., Withern, Lincs. (2)
5. Moranagher Trout Farm (M.A.F.F. - N.I.), Kilrea, Co. Antrim (1)
6. Silver Stream Fisheries Ltd., Clough, Co. Antrim (1)
7. Somerset Water Board, Durleigh Reservoir Hatchery, Durleigh (1)

8. Trafalgar Estates Ltd., Bodenham, Wilts. (2)
9. Trawsfyndd Lake Hatchery, Brecon (1)
10. Trent Valley Trout Farms, Mercaston, Derbyshire (1)
11. Two Lakes, Romsey, Hants. (3)
12. Vortex Ltd., Meriden, Warwickshire (1)
13. Water Mill Trout Farm Ltd., Louth, Lincs. (1)

III. Republic of Ireland

1. Dingle Trout Farm Ltd., Dingle, Co. Kerry (1)
2. Glenfield Trout Farm, Glen of Aherlow, Co. Tipperary (1)
3. Goatsbridge Trout Farm, Thomastown, Co. Kilkenny (1)
4. Irish Hydro-electric Board Hatchery, River Shannon(1)
5. Irish Trout Industries Ltd., Arklow, Co. Wicklow (2)

IV. Denmark

1. Dollerup Damkultur, Skelhøje (1)
2. Dollerup Damkultur, Viborg and Hallum (2)
3. Forsøgsdambruget, Brøns (2)
4. Klapmølle Dambrug, Ringkøbing and Lem (2)
5. Løvet Dambrug, Bryrup (1)
6. Nymølle Dambrug, Hojmark (1)
7. Vingforel A/S, Vejle (1)
8. Various farms at Esbjerg, Varde and Viborg (1)

V. Italy

1. Trota Piare Sile, Pordenone (1)
2. Trota Piare Sile, Treviso (1)
3. Troticolture Cappello, Borgo Valsugana (1)
4. Troticolture Cappello, Trento (1)
5. Troticoltura Mulino Vecchio, Cerano (1)

VI. Norway

1. Norsk Hydro, Lundamo (1)
2. Rylandsråg Fiskeri A/S, via Bergen (1)

VII. West Germany

1. Bad-Oldesloe, Lübeck (1)
2. Bayerische Biologischen Versuchsanstalt, Wielenbach (1)

3. Bundesforschungsanstalt für Fischerei, Eckenförde (1)
4. Herr Muller, Hannover (1)
5. Sarlhusen, Neumunster (1)

B. FISH DISEASE PROBLEMS

1. Bayerische Biologischen Versuchsanstalt, Grosslappen, West Germany (1)
2. Centro Studio Malattie Pesci, (I.Z.S.P.L.), Torino, Italy (1)
3. Den Klg. Ambulatoriske, Veterinaerehøjskole, Københarn, Denmark (1)
4. Dept. of Veterinary Pathology, University of Glasgow, Scotland (3)
5. Institute of Zoology and Parasitology, Munich University (1)
6. State Veterinary Laboratory, Oslo, Norway (2)
7. Veterinaers Serumlaboratorium, Aarhus, Denmark (1)
8. Veterinary Research Laboratory, Abbotstown, Dublin (1)

C. FISH NUTRITIONAL PROBLEMS

1. C.N.P. Speciality Products Ltd., Witham, Essex (1)
2. Dansk Ørredfoder A/S, Brande, Denmark (2)
3. Institute of Marine Biochemistry, Aberdeen (1)
4. Institute for Research into Animal Nutrition, Putten, Holland (1)
5. Pauls and Whites Foods Ltd., Ipswich (2)
6. Trouw and Co. (Great Britain) Ltd., Harston, Cambridge (2)
7. Vitamin Research Institute, Bergen, Norway (1)

D. EEL CULTURE

1. Bundesforschungsanstalt für Fischerei, Hamburg (1)
2. Toome Eel Fishery, Toome Bridge, Co. Antrim (1)

E. FISH GENETICS

1. Bundesforschungsanstalt für Fischerei, Hussenstelle Ahrensburg (1)
2. University of Agriculture, Ås, Norway (1)

F. FISH PROCESSING

1. Dantrout, Brande, Denmark (1)
2. S. N. Jøker A/S, Ny Harn, Esbjerg, Denmark (1)
3. Moray Fish Supply Co. Ltd., Buckie, Banff (1)
4. Vestlandske Salslag A/S, Bergen, Norway (1)

G. FISH MARKETING

1. Associated Fisheries Ltd., Thornton Heath, Surrey (2)
2. Billingsgate Fish Market, London (3)
3. Compass House Ltd., Grimsby, Lincs. (1)
4. Cranfield Institute of Technology, Bedford (1)
5. Financial Times House, London (1)
6. Findus Ltd., Croydon, Surrey (1)
7. Fishmongers' Company, London (2)
8. Janssens Ltd., London, E.C.4. (2)
9. Mac Fisheries Ltd., Bracknell, Berks, (2)
10. Manchester Wholesale Fish Market, Manchester (2)
11. Ministry of Agriculture, Fisheries and Food, London (3)
12. Peabody Foods Ltd., London (1)
13. Ross Foods Ltd., Grimsby, Lincs. (2)
14. Unilever, London (1)

H. ECONOMICS OF FISH FARMING

1. L. Berge Esq., Strandebarm, Norway (2)
2. Industrial Development Unit, White Fish Authority, Hull (2)
3. Dept. of Production Engineering, University of Birmingham (1)

I. WHITE FISH CULTURE

1. White Fish Authority, Ardtoe (4)
2. White Fish Authority, Hunterston (2)
3. White Fish Authority, London (2)

J. SHELLFISH CULTURE

1. Bond Iascaigh Mhara, Dublin (1)
2. Constructors John Brown, Portsmouth, Hants. (1)

3. Dept. of Agriculture and Fisheries, Field Station, Feint, Co. Kerry (1)
4. Lt. Cdr. M. Ingram, Hinkley Point Power Station, Devon (1)
5. Kinlochbervie Shellfish Co. Ltd., Kinlochbervie, Sutherland (1)
6. Ministry of Agriculture, Fisheries and Food, Conway (3)
7. Mr. Moscati, Tain, Ross-shire (1)
8. Poole Oyster Co. Ltd., Poole, Dorset (1)
9. Scottish Sea Farms, Ledaig, by Oban (1)
10. Severnside Co. Ltd., Patchway, Bristol (1)
11. T. P. Stevenson, Esq., Lochgilphead (1)
12. University College Galway, Galway (1)
13. White Fish Authority (Shellfish Culture Unit), Conway (3)

K. THERMAL EFFLUENTS AND FISH CULTURE

1. Central Electricity Generating Board, Fawley (1)
2. " " " " Leatherhead (1)
3. " " " " Llandudno (2)
4. " " " " London (1)
5. South Scottish Electricity Board, East Kilbride (1)

L. MISCELLANEOUS

1. Chr. Michelsens Institutt, Bergen (2)
2. Den Vitenskapelige Ardeling, Vollebekk (2)
3. Dept. of Agriculture and Fisheries, Dublin (2)
4. Dept. of Agriculture and Fisheries for Scotland, Aberdeen (2)
5. Dept. of Agriculture and Fisheries for Scotland, Edinburgh (1)
6. Direktoratet for Jakt, Vildstellog Ferskrannsfiske, Trondheim (1)
7. Dunstaffnage Laboratory (S.M.B.A.), Oban (5)
8. Fisheries Laboratory (M.A.F.F.-N.I.) Coleraine (1)
9. Dr. C. F. Hickling, London (2)
10. Highlands and Islands Development Board, Inverness (7)
11. Inland Fisheries Trust, Dublin (1)
12. Institute of Marine Research, Bergen (2)
13. Ministry of Agriculture, Fisheries and Food: Fisheries Lab., London (1)

14. Ministry of Agriculture, Fisheries and Food: Torry Research Station, Aberdeen (1)
15. Syndicat des Pisciculteurs de France, Paris (1)
16. Unilever Research Laboratory, Aberdeen (1)
17. University of Edinburgh (Dept. of Forestry and Natural Resources (2)
18. University of Southampton (Dept. of Zoology & Oceanography)(1)
19. University of Strathclyde (Dept. of Civil Engineering) (1)

N.B. (i) Total number of visits made = ca. 214

(ii) Figures in parentheses indicate number of visits/location.

APPENDIX III

Projections from length data. I

Fish 1 inch on 1st December

	Length (inches)	No. per lb.	1000 Fish (lbs.)
31st Dec.	1.34	1010	0.99
31st Jan.	1.62	600	1.67
28th Feb.	1.81	430	2.32
31st Mar.	1.90	359	2.78
30th Apr.	2.11	260	3.84
31st May	2.39	182	5.49
30th June	2.97	98.6	10.14
31st July	3.89	42.4	23.6
31st Aug.	5.00	19.7	50.7
30th Sept.	5.89	12.1	82.6
31st Oct.	6.62	8.65	115.8
30th Nov.	7.08	6.90	144.9
31st Dec.	7.42	6.00	166.5
31st Jan.	7.71	5.38	185.9
28th Feb.	7.90	5.00	200.0
31st Mar.	7.99	4.83	206.7
30th Apr.	8.20	4.47	223.8
31st May	8.48	4.05	247.0
30th June	9.06	3.32	301.2
31st July	9.98	2.47	404.6*
31st Aug.	11.09	1.80	555.4

* ½lb. weight (10.71") on 20th August

Projections from length data. II

Fish 1 inch on 1st January

	Length (inches)	No. per lb.	1000 Fish (lbs.)
31st Jan.	1.28	1181	0.85
28th Feb.	1.47	773	1.29
31st Mar.	1.56	653	1.53
30th Apr.	1.77	444	2.26
31st May	2.05	286	3.50
30th June	2.63	136	7.36
31st July	3.55	55.2	18.11
31st Aug.	4.66	24.4	41.00
30th Sept.	5.55	14.43	69.2
31st Oct.	6.28	9.94	108.0
30th Nov.	6.74	8.06	124.1
31st Dec.	7.08	6.92	144.6
31st Jan.	7.36	6.17	162.1
28th Feb.	7.55	5.73	174.4
31st Mar.	7.64	5.55	180.3
30th Apr.	7.85	5.10	196.2
31st May	8.13	4.59	218.1
30th June	8.71	3.71	269.7
31st July	9.63	2.75	363.8
31st Aug.	10.74	1.98	504.5

½lb. weight (10.71") on 31st August.

Projections from length data. III

Fish 1 inch on 1st February

	Length (inches)	No. per lb.	1000 Fish (lbs.)
28th Feb.	1.19	1580	0.63
31st Mar.	1.28	1150	0.87
30th Apr.	1.49	740	1.35
31st May	1.77	445	2.25
30th June	2.35	190	5.26
31st July	2.27	70.6	14.17
31st Aug.	4.38	29.3	36.65
30th Sept.	5.27	16.85	59.4
31st Oct.	6.00	11.41	87.5
30th Nov.	6.46	9.15	109.2
31st Dec.	6.80	7.85	127.3
31st Jan.	7.08	6.94	144.1
28th Feb.	7.27	6.42	155.9
31st Mar.	7.36	6.16	162.4
30th Apr.	7.57	5.69	175.9
31st May	7.85	5.10	196.1
30th June	8.43	4.12	242.8
31st July	9.35	3.04	329.6
31st Aug.	10.46	2.14	466.5
30th Sept.	11.35	1.68	595.0

½lb. weight (10.71") on 8th September

Projections from length data. IV

Fish 1 inch on 1st March

	Length (inches)	No. per lb.	1000 Fish (lbs.)
31st Mar.	1.09	1950	0.51
30th Apr.	1.30	1125	0.89
31st May	1.58	620	1.61
30th June	2.16	249	4.01
31st July	3.08	83.4	11.99
31st Aug.	4.19	33.7	29.7
30th Sept.	5.08	18.7	53.5
31st Oct.	5.81	12.6	79.4
30th Nov.	6.27	10.0	100.0
31st Dec.	6.61	8.5	117.8
31st Jan.	6.89	7.54	132.9
28th Feb.	7.08	6.94	144.2
31st Mar.	7.17	6.68	149.9
30th Apr.	7.38	6.14	163.0
31st May	7.66	5.49	182.2
30th June	8.24	4.41	226.5
31st July	9.16	3.21	311.8
31st Aug.	10.27	2.26	443.0
30th Sept.	11.16	1.77	565.0

½lb. weight (10.71") on 15th September

Projections from length data. V

Fish 1 inch on 1st April

	Length (inches)	No. per lb.	1000 fish (lbs.)
30th Apr.	1.21	1380	0.72
31st May	1.49	745	1.34
30th June	2.07	294	3.40
31st July	2.99	92.5	10.81
31st August	4.10	35.7	28.01
30th Sept.	4.99	19.8	50.50
31st Oct.	5.72	13.2	75.70
30th Nov.	6.18	10.4	96.1
31st Dec.	6.52	8.89	112.6
31st Jan.	6.80	7.85	127.3
28th Feb.	6.99	7.21	138.6
31st Mar.	7.08	6.93	144.2
30th Apr.	7.29	6.37	157.1
31st May	7.57	5.68	176.0
30th June	8.15	4.56	219.0
31st July	9.07	3.30	303.0
31st Aug.	10.18	2.33	430.0
30th Sept.	11.07	1.81	552.0

½lb. weight (10.71") on 19th September

Projections from length data. VI

Fish 1 inch on 1st May

	Length (inches)	No. per lb.	1000 fish (lbs.)
31st May	1.28	1175	0.85
30th June	1.86	380	2.63
31st July	2.78	116	8.62
31st Aug.	3.89	42.3	23.6
30th Sept.	4.78	22.5	44.5
31st Oct.	5.51	14.8	67.5
30th Nov.	5.97	11.6	86.2
31st Dec.	6.31	9.81	102.0
31st Jan.	6.59	8.63	115.9
28th Feb.	6.78	7.92	126.2
31st Mar.	6.87	7.60	131.7
30th Apr.	7.08	6.93	144.3
31st May	7.36	6.17	162.1
30th June	7.94	4.94	202.5
31st July	8.86	3.55	281.9
31st Aug.	9.97	2.48	403.5
30th Sept.	10.86	1.92	521.0

½lb. weight (10.71") on 26th September

Projections from length data VII

Fish 1 inch on 1st June

	Length (inches)	No. per lb.	1000 Fish (lbs.)
30th June	1.58	629	1.59
31st July	2.50	158	6.33
31st Aug.	3.61	52.0	19.2
30th Sept.	4.50	27.1	36.9
31st Oct.	5.23	17.85	56.0
30th Nov.	5.69	13.42	74.5
31st Dec.	6.03	11.25	88.9
31st Jan.	6.31	9.81	102.0
28th Feb.	6.50	8.97	111.6
31st Mar.	6.59	8.63	116.0
30th Apr.	6.80	7.85	127.3
31st May	7.08	6.95	143.9
30th June	7.66	5.49	182.3
31st July	8.58	3.90	256.3
31st Aug.	9.69	2.70	270.3
30th Sept.	10.58	2.07	484.0
31st Oct.	11.31	1.70	588.0

½lb. weight (10.71") on 6th October

APPENDIX IV

TROUVIT GROSS ANALYSES AND PARTICLE SIZES

		ENGLISH			DUTCH		FRENCH		
		A	B	C	A	B	A	B	C
oil	%	8.41	8.62	8.62	8.38	8.54	6.56	6.12	5.88
fibre	%	1.79	2.54	3.02	1.81	2.56	1.84	2.37	2.41
crude protein		49.8	46.8	43.1	49.9	46.8	51.3	46.5	42.6
lysine	%	3.54	3.26	2.92	3.48	3.14	3.62	3.14	2.81
methionine	%	1.17	1.09	0.96	1.14	1.03	1.17	1.00	0.89
cystine	%	0.58	0.57	0.54	0.57	0.56	0.60	0.56	0.52
calcium	%	2.09	1.89	1.59	2.03	1.76	2.83	2.65	2.47
phosphorus	%	1.47	1.43	1.31	1.45	1.38	1.87	1.77	1.64
salt	%	1.70	1.59	1.33	1.60	1.69	1.87	1.72	1.52

Pellet Size									**Fish Size**
000 *				+		+			
00 *				+		+			0.5g.
0 * 1.2 mm.				+		+			0.5 - 5.0 g.
1 * 1.7 mm.				+		+			5.0 - 20.0 g.
2 2.1 mm.				+			+		20.0 - 65g.
3 3.5 mm.		+	to		+			+	65.0 - 135g.
4 5.0 mm.		+	be		+			+	135.0 - ?
5 7.5 mm.			decided						to be
6 10.0 mm.									decided

* - Crumbs

MASTER FORMULATION SHEET FOR TROUVIT "A" 000 - 2

Analysis per unit	Ton	Material
Vit. A m.i.u.	22.75	Herring meal - Danish
" D 3 m.i.u.	4.409	Fish meal - South African
" B 1 gm	10.0	Beef greaves - Type F.
" B 2 gm	20.0	Blood meal - S. D. Swedish
" B 12 mgm	25.0	Fodder yeast
Nicotinic Acid gm	125.0	Soya bean meal - 50% C.P.
Ca-d- Pant gm	49.5	Oat groats - Type T
Choline Chloride gm	1000	
Folic gm	2.0	Durabond
Vit. E i.u.	50000	
Vit. K gm.	3.0	Di-cal-phos
Inositol gm.	250	Salt
Biotin gm	0.4	
Vitamin C gm	500	Trouvit fat basemix
P.A.B.A. gm	250	
B.H.T.(3½ oz.) gm	100	Trouvit vit/min basemix
Penicillin gm	-	
Methionine gm	1000	
		Wheatfeed
Iron gm	36.0	
Cobalt gm	0.8	
Manganese gm	35.0	
Iodine gm	1.36	
Zinc gm	25.0	
Copper gm	5.0	
Magnesium gm	100.0	
Solenium gm	0.135	

APPENDIX V (Sample input & output data for NPV72 file).

A. Sample input file:

```
100 11,4,.425,.1,
110 0,256,0,0,.10,0,10
120 0,50,1,0,.33,0,3
130 4,50,1,0,.33,0,3
140 7,50,1,0,.33,0,3
150 o,366.2,0
160 13.4,0,0
170 147,0,0
180 147,0,0
190 147,50,0
200 147,0,0
210 147,0,0
220 147,50,0
230 147,0,0
240 147,0,0
250 147,0,0
260 o,0,0
```

B. Sample output file:

```
Net Present Value Calculation Program
Rate of return = 10%; Tax rate = 42.5%
YEAR      SLI      DBI      TP      TWDA      NCF      CNPV

0         256.     50.      0.       0.      -366.     -366.
1                           0.      42.       -31.     -395.
2                           0.      37.        75.     -332.
3                           9.      26.        58.     -289.
4                  50.     14.      26.        -6.     -293.
5                           0.      43.        68.     -250.
6                           7.      37.        51.     -222.
7                  50.      9.      26.         8.     -217.
8                           0.      42.        68.     -186.
9                           7.      37.        51.     -164.
10                          9.      26.        58.     -142.
11                         14        0.       -14.     -146.
     NET PRESENT VALUE = -146
```

Legend:

SLI = Straight-line depreciated investment

DBI = Declining balance " " " "

TP = Tax paid

TWDA = Total written-down allowance

NCF = Net cash flow

CNPV = Cumulative net present value

NB. All values are in £ x 1,000