AN APPRAISAL OF COMMERCIAL OYSTER CULTURE IN THE UNITED KINGDOM

Thesis submitted for the degree of
Doctor of Philosophy

by

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January 1982

Graduation June 1982

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ABSTRACT

This study presents a detailed technical and economic investigation of the culture of both the Native Flat Oyster (*Ostrea edulis*) and Pacific Cupped Oyster (*Crassostrea gigas*). The work is inter-disciplinary in its approach.

Criteria for the selection of ongrowing technique and site selection have been established. Information published on oyster performance in the sea has been employed to develop deterministic computer simulation models of oyster growth and mortality under different conditions. Models based on the von Bertalannfy growth equation and a multiple regression equation have been derived. The latter employs oyster size and seawater temperature as determinants of oyster growth rate.

A comprehensive set of costs associated with oyster culture has been prepared. Together with the multiple regression model these costs have been used to perform investment appraisals by the Internal Rate of Return method on oyster cultivation projects.

Production schedules together with market time predictions are presented for projects to cultivate each species of oyster. The effects of species, mortality rate and temperature regime on the commercial viability of oyster culture has been studied in detail. The appraisal demonstrates the value of sensitivity analysis in evaluating aquaculture projects.

The present status of the market for oysters is discussed with emphasis on the sale of the Native Flat Oyster. A future marketing strategy for cultivated oysters is proposed.

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ACKNOWLEDGEMENTS

I would like to thank my supervisors, Dr R Ball, Dr P J W N Bird and Dr A J Redshaw for all their help and encouragement; also Mr M Makower for the use of facilities to write this thesis.

Special thanks are due to the scientists, individuals and companies associated with aquaculture who have provided information. Their contribution is gratefully acknowledged.

I am indebted to the SRC/SSRC for providing a studentship to fund this study.

Finally I would like to thank Miss Janet M Crabb for typing the manuscript.

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INTRODUCTION

1.1 AQUACULTURE

Aquaculture is the farming or husbandry of aquatic animals and plants. The important distinction between it and fishing is that man attempts to provide or enhance conditions which favour higher yields than would naturally occur. Fishing is a purely hunter-gatherer activity. In most cases cultivation involves intervention in natural ecological dynamics and the removal and isolation of subsystems.

Early attempts at cultivation were primarily extensive in nature. Large areas being farmed with a low stock density and much reliance on natural productivity. Such methods exercise little control over natural systems and are susceptible to losses due to adverse environmental changes. Intensive rearing systems hold organisms at high densities, in small units with total dependence on supplies of feed. This provides a much greater degree of control but at the expense of higher capital and operating costs. The effort and technical knowledge required for successful, intensive mariculture tends to increase with tropic level and the complexity of the cultured animal's life-history. For most omnivorous and carnivorous species with potential for cultivation expenditure on the development of extensive culture methods would not be justified.

The bulk of farmed fish production in the United Kingdom is intensive and output stands currently at approximately 5,000 metric tonnes per annum. This represents an annual turnover in the industry of about £10 million (Purdom, 1979). Most of this output is of trout and the majority of production is in the hands of a few large producers (Lewis, 1979). The fishing industry in the UK lands 900,000 - 1,000,000 metric tonnes per year and by comparison fish farming output is insignificant. Farm production is predicted to reach 15,000 - 20,000 tonnes by the year 1985. However, the immediate potential of aquaculture has been overstated frequently and commercially viable operations have not developed as rapidly as anticipated. The industry in this country is approximately fifteen years old and this is a scant basis for prediction of the future. The situation is bedevilled by the diversity of operations and experience from which it is almost impossible to forecast accurately. Future expansion of aquaculture in the UK is likely to be arithmetic rather than geometric. The modest prediction given above might be considered optimistic in the present economic climate.

Fish farming in this country is centred on the so-called 'luxury' species: salmon, trout and oysters. The choice of species has been governed from the outset by the need for profitability and by the state of knowledge about individual species. Technical expertise is abundant in the UK, so much so that the export of technical knowledge and consultancy services has been one of the most successful sectors of the aquaculture industry (Pullin, 1977). Unfortunately this strength has not always been matched by entrepreneurial and marketing skills.

1.2 THE DEVELOPMENT OF AQUACULTURE

The early advocates of fish farming emphasised three main reasons for developing aquaculture:

1. It is potentially a vast source of inexpensive protein food.
2. It will substitute for declining fish stocks.
3. It is a highly lucrative business.

1.2.1 A source of inexpensive protein food

Aquaculture has sometimes been regarded as a means of providing vast amounts of food to a protein-starved world. To date this has not been achieved, only about 10% of the world finfish and shellfish catch is produced from aquacultural practices (Trapper, 1980). Fish farming as a source of protein is important in China, Asia and Africa where herbivorous fish such as carp, this country is approximately fifteen years old and this is a scant basis for prediction of the future. The situation is bedevilled by the diversity of operations and experience from which it is almost impossible to forecast accurately. Future expansion of aquaculture in the UK is likely to be arithmetic rather than geometric. The modest prediction given above might be considered optimistic in the present economic climate.

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1.2.1 <u>A source of inexpensive protein food</u>

Aquaculture has sometimes been regarded as a means of providing vast amounts of food to a protein-starved world. To date this has not been achieved, only about 10% of the world finfish and shellfish catch is produced from aquacultural practices (Trapper, 1980). Fish farming as a source of protein is important in China, Asia and Africa where herbivorous fish such as carp, milkfish and tilapia are cultured. The world catch of freshwater finfish in 1979 was 5.1 million metric tonnes, a significant element of which was cultured.

Fish farming in the British climate is centred on species with a high unit value rather than the mass-production of low-cost protein. Whilst being a commercially feasible operation it will have a minimal effect upon our food supplies. In the UK fish only contributes 4 - 5% of our dietary protein and farmed fish accounts for only 0.5% of the total fish catch.

The intensive cultivation of trout is a net user of protein, not a net producer. To produce 1 tonne of farmed fish may require up to 5 tonnes of trash fish processed as fishmeal (McAnuff, 1980). Fish have high conversion efficiencies but have slow growth rates. They are poikilotherms (cold-blooded) and live supported in an aqueous medium and as such do not require much energy to maintain their body state. This advantage, however, is offset by a longer time to reach market size compared to other farmed animals. For example it requires 1 - 2 years to produce a 'plate-size' turbot to serve one person. To produce a chicken to provide a meal for a family of four takes approximately nine weeks. The production costs of farmed fish in Britain, although falling, are still high compared to some farmed animals:

Average Production Cost:	Trout	£0.90/kg
(McAnuff, 1979)	Broiler Chicken	£0.44/kg

In this country consumer preference is for carnivorous species of finfish. To increase significantly our protein supply would require a change in attitude and taste in favour of coarse fish and shellfish. Vastly increased production is prohibited by ambient water temperatures and competition with other users for suitable farm sites.

1.2.2 A substitute for declining fish stocks

The nominal fish catches for the UK in the last decade have fallen from a peak in 1973 of 1,129,700 metric tonnes to a level of 905,101 tonnes in 1979. This decline in the industry has come about for a combination of reasons.

Overfishing of North Sea herring and West Coast mackerel has hit the inshore fleet. Entry into the European Economic Community (EEC) and subsequent protracted negotiations over a Common Fisheries Policy has increased fishing pressure on British grounds. At the same time certain deep-water grounds have been closed to the British fleet. Fuel costs have escalated. The cost of gas oil used by the fleet increased in 1980 by 19% and since the beginning of 1979 the total increase has been 74% (MacSween, 1980). In the first half of 1980 the average price paid for fish such as cod and haddock actually fell by 12% compared to the previous year. Imports of fish from countries where fishing is heavily subsidised and the consumer's preference for 'convenience' rather than fresh fish have also adversely affected the industry.

At present aquaculture offers no hope of arresting this decline. The species cultivated supplement rather than substitute for the harvest of the fishing fleet. The volume and potential of farmed fish and shellfish is too small to significantly affect the industry as a whole. The recent development of important shellfisheries for the Norway Lobster (*Nephrops norvegicus*) and the Scallop (*Pecten maximus*) are valuable alternative fisheries for the inshore fleet but are not aquaculture.

1.2.3 Aquaculture as a highly lucrative business

Fish farming is an infant industry with attendant inefficiencies, problems and highly variable profitability. At present the industry is composed mainly of 'cottage' enterprises and employs at most, a few thousand people in total. The profitability of aquaculture is variable, water availability and temperature being crucial determinants of production costs. The cost of producing 1lb of trout may vary from 30p to 100p depending on the farm (Purdom, ibid). The average labour productivity is low: most trout farms achieve 10 - 20 tonnes of fish per year per full-time employee (Parker, 1979).

The cost of captured fish depends on the availability of natural stocks, access to stocks and the cost of capture. The landed price of captured fish will almost inevitably rise in the future due to the interaction of these three elements. The cost of farmed fish is likely to fall as methods, yields and scales of operation improve.

The immediate opportunity for aquaculture in the United Kingdom is to fill market gaps for certain high value species which offer sufficiently high returns on investment to offset the inherent high risks involved. At present the markets for such species are small and under-developed.

1.3 THE SELECTION OF POTENTIAL SPECIES FOR AQUACULTURE

The potential of a species for cultivation should be considered in terms of biological, technical and economic criteria. The resource must be present and available in quantities that can be exploited commercially. The culture system must be able to produce, on a regular basis, fish or shellfish of a consistent size and quality within an acceptable time scale. In this respect the culture of indigenous species has much to recommend itself. Furthermore economic factors such as marketability and price act as constraints and limit the possibilities for aquaculture which is technically feasible.

The EEC Aquaculture Working Group has identified eleven indigenous species as being of major importance for culture in the UK (Kirk, 1979). A bioeconomic matrix for assessing the suitability of ten of these species for mariculture has been drawn up (Figure 1.1). The remaining species, the Ormer (*Haliotis tuberculata*), is only found in appreciable quantities in the Channel Isles and is more typical of Mediterranean rather than British fauna.

Although the criteria list employed in the matrix is not exhaustive it covers the main factors relevant to aquaculture. This simple ranking system clearly highlights the potential of

Figure 1.1 Factor matrix for assessing the suitability of animals for mariculture in the United Kingdom

SELECTION CRITERIA	SPECIES								
	Finfish			Molluscs				Crustaceans	
	Salmonids	Flatfish	Eels	Oysters	Mussels	Clams	Scallops	Lobster	Shrimps
Carnivores *	2	2	2						
Phytoplankton Filter Feeders *				5	5				
Detritus/ Scavangers *						4	4	4	4
Controlled Spawning Possible	5	4	3	5	5	5	4	3	1
Mass produced in Hatchery	5	5	2	5	5	5	4	4	4
Fast Growth Rate Potential	5	4	2	5	5	4	4	4	4
Satisfactory Feed Known	5	3	5	5	4	4	3	3	3
High Conversion Efficiency	5	4	5	2	2	2	2	3	3
Hardy in Captivity	5	5	5	5	5	3	3	3	3
High Disease Resistance	4	4	4	4	4	4	4	4	3
High Culture Density Potential	4	4	5	5	5	5	5	3	3
Farm System Developed	4	4	5	5	5	3	3	2	4
High Price Range	5	3	5	5	2	4	4	5	4
Marketability	5	4	3	5	4	3	4	5	5
MATRIX SCORE	54	46	46	56	51	46	44	43	41

* Trophic efficiency

Based on Kinne (1976)

Key: 1 not suitable
5 suitable
2 - 4 intermediate scoring

two groups in particular, the salmonidae and oysters. It is towards the culture of these vastly different animals that most research activity has been directed. These species now account for the bulk of the UK aquaculture production. Certain problems still remain with the cultivation of the other species in the matrix. For example the cannibalistic nature of juvenile lobsters has yet to be overcome on a commercially viable basis. In this study an attempt is made to briefly review the present status of the fisheries and cultivation of both crustacean and molluscan shellfish (Appendix I). It is these species which use similar culture techniques or compete in the same market as oysters.

1.4 PRESENT STATUS OF SHELLFISHERIES IN THE UNITED KINGDOM

In 1979 the world nominal catch of all aquatic organisms was 71.3 million tonnes. Molluscs accounted for 4,976,000 tonnes and Crustaceans 3,066,000 tonnes of total landings (FAO, 1980). The bulk of shellfish landings are of marine origin. Fresh-water molluscs only represent 4 - 5% of the total mollusc catch and none are recorded in the British Isles.

In the United Kingdom shellfish landings in 1979 accounted for 7.7% of the total recorded landings. The shellfish catch has risen markedly in post-war years reaching a peak of 82,212 tonnes in 1976. The establishment of commercial fisheries for the Norway Lobster and scallops accounts for a significant element of this increase. The 1979 landings for shellfish are shown in Table 1.1. The fisheries and cultivation of individual species are discussed later.

Traditionally the oyster is the most valuable shellfish. Over-fishing, disease and severe weather have all served to reduce the natural oyster stocks to a fraction of their level in the last century. The fishery is based on the Native Flat Oyster (*Ostrea edulis*) for which fishing is only permitted between the months September to April. During the summer the sale of

Table 1.1 Landings of Shellfish by British and Foreign Vessels in 1979

Species	Landings (tonnes)	Value (£000)	Price/ Tonne
A Crustacea			
Crabs*	11,717	4,388	£ 374.5
Lobster*	872	4,536	5,201.5
Norway Lobster*	16,400	22,648	1,381.0
Shrimps and Prawns	1,751	1,271	726.0
B Molluscs			
Cockles	10,415	504	48.5
Mussels	5,510	271	49.0
Oysters	680	1,033	1,519.5
Periwinkles	3,229	747	231.5
Queens*	7,718	1,671	216.5
Scallops*	9,007	4,742	526.5
Whelks	1,785	261	146.0
Squid*	374	386	1,032.0
C Other Shellfish	315	405	1,285.5
ALL SHELLFISH	67,757	42,839	£ 614.0

Source: FAO (1980)

* Includes landings of the Channel Isles and Isle of Man.

oysters was maintained, at a low level, by the sale of the Portuguese Oyster (*Crassostrea angulata*). The seasonal nature of the fishery and relative scarcity of oysters ensured that the high unit price and 'luxury' image were maintained. Molluscs in general, however, are not highly regarded by the British consumer.

In the 1960s techniques were developed, principally by the Ministry of Agriculture, Food and Fisheries (MAFF), to spawn artificially and rear oyster spat under hatchery conditions. This breakthrough together with the introduction of the faster growing Pacific Cupper Oyster (*Crassostrea gigas*) freed the industry from its dependence on natural spatfalls and made commercial cultivation feasible. Commercial development has centred on the inter-tidal culture of *C. gigas* with raft culture being restricted to the more sheltered sites. A recent estimate suggests that about 40 enterprises are actively engaged in the culture of *C. gigas* and an equal number engaged in trials (Walne and Helm, 1979). In 1975 the industry output was approximately 29 tonnes, by 1976 it had risen to 150 tonnes and in 1979 was estimated to be 300 tonnes.

The industry has only been established for seven or eight years and has developed in an *ad hoc* manner. With its present structure and dispersed nature the industry is ill-equipped to produce the number of oysters necessary to encourage investment in the development of new shellfish-based products by food processors. Short-term expansion is likely to be gradual but there is considerable scope to increase supplies to existing markets and to develop new outlets. Such development will, however, depend upon close control over costs and a more rigorous approach to the management of the cultivation units.

The expansion of cultivation has been parallelled by the re-emergence of the Solent as a significant oyster fishery. The fishery is currently valued at £1 million per annum, supports some 450 vessels and provides approximately 700 men with a substantial part of their income (Key and Davidson, 1981).

1.5 THE USE OF MODELLING TECHNIQUES IN AQUACULTURE

In complex systems it is normally impossible or impractical to investigate all possible interactions by experimentation. In such circumstances it is necessary to develop models which represent the most important aspects of the systems and which may be used to simulate the behaviour of those systems. In this study, because of the time scale of the oyster growing period and research facilities available, field-growth trials were ruled out.

In recent years access to computer facilities has stimulated the use of models and simulation techniques by research workers. Growth models are commonly used in biology but their application to harvesting situations is a relatively recent development. In aquaculture computer simulation is potentially a quick, inexpensive tool for evaluating the effects of different management strategies. Particular areas such as optimisation of stock management, production scheduling and training of managers stand to gain considerably from the employment of management techniques.

Any model is an abstraction from reality yet it is required to give a realistic representation of the system it describes. The key to effective simulation is to strike a proper balance between realism and abstraction. It is not always the case that complex models are a more useful tool than simple models. The latter are often sufficient to elucidate the interactions and the magnitude of the effects of changes in conditions. Imperfect models of any type serve to pinpoint gaps in our knowledge and, therefore, act as stepping stones to the construction of improved models. In biological systems where interactions and interdependencies are often both complex and poorly understood a simple model is often preferable. The model developed in this study is not all-embracing but covers those variables of interest to the culturist.

Once an appropriate model has been derived a well-defined, attainable set of management objectives must be established if alternative management strategies are to be evaluated. The limited application of management techniques in aquaculture to date may be attributable to an incomplete understanding of the biology of the organism and of the techniques themselves. A brief description of some appropriate studies may serve to show the potential value of such work.

In an attempt to achieve regular, year-round production of rainbow trout (*Salmo gairdneri*) of a consistent size and quality the British Oxygen Company have developed a computer programme to optimise stock management at their Shearwater site (Whitehead et al, 1980). The model is based on an annual production of 48 tonnes of table trout (275g size) with a growing period of 12 - 24 months. The model computes fish growth as a function of food consumed and food conversion ratio. The two major factors affecting fish growth, water temperature and fish size are also considered since these parameters are used to determine the feeding level employed. The model is used to generate predictive data upon which to base decisions on both the number and most appropriate timing of introductions of eggs and fry into the farm in order to obtain a continuous production cycle.

Optimisation models have been employed by some workers. This technique involves the formulation of an objective function or performance measure that is maximised or minimised by varying the decision variables over which the culturist has control. Huang et al (1976) developed a dynamic simulation model for populations of prawns (*Macrobranchium rosenbergii*) in culture ponds. The prawn population model predicted numbers of prawns of each sex and their size distribution at each harvest period. The model may be used to predict the number of prawns ready for harvest at any time. Optimisation methods have been used in theoretical studies of the culture of the American lobster (*Homorus americanus*) (Rauch et al, 1975; Allen and Johnson, 1976). This species was selected in view of the wealth of data available to define an initial model and since lobster culture incorporates nearly every kind of environmental manipulation required in culture systems.

In the United Kingdom the White Fish Authority (WFA) in the early 1970s investigated the commercial potential of seed mollusc production in a hatchery (Haywood and Curr, 1970; Curr, 1974). This work was a straightforward application of linear programming to optimise the profitability and production scheduling of a proposed hatchery of five million spat per annum capacity. The two species considered *O. edulis* and *C. gigas* share the same production facilities but differ greatly in the capacity required. Differences occur in spat survival, growth rate and tolerance of low water temperatures. Direct costs of spat production depend on species, month of hatching and marketing size. Similarly the revenue accrued will be determined by these factors.

The model developed contained 32 variables from which the production pattern could be selected. Imposed on the model were 40 constraints relating to the capacity of all processes, market restrictions, limited production of less popular sizes, forced minimum quotas of certain sizes in the solution, and labour constraints.

The investment appraisal carried out on the proposal revealed that a capital investment of £44,000 (1969 prices) would be required and that the hatchery would generate a net profit before tax of £7,600 pa. The production schedules produced by the model were used in the hatchery which was constructed at Brynsiencyn, Anglesey.

In the present study a deterministic model of the growth of oysters in the sea has been derived and used to simulate the operation of a unit to produce 100,000 oysters pa. of 70 grammes or over. The use of a deterministic approach to simulation assumes that exact relationships between system components are known. This approach is most useful when variation in the system under consideration is largely described by the modeller. Large amounts of unexplained variation will substantially decrease the utility of deterministic models (Hammond and Lackey, 1976). Under such circumstances stochastic processes may be employed to generate random elements to account for the inclusion of factors which cannot be exactly predicted. There is ample data from which to establish the variability of the important parameters and include this in a deterministic model of oyster cultivation. In this study sensitivity analysis is used to investigate the effect of changing variables in the deterministic model. Where appropriate assumptions made in the analysis are stated.

There is abundant information in the literature concerning the growth pattern of oysters in the sea. This information has been used to derive a multiple regression model describing oyster growth as a function of seawater temperature and oyster size. A time step of one month is used as this represents the smallest interval over which the independent variables can be reliably recorded. At present there is insufficient quantitative data regarding the growth of oysters in the sea and the food value of phytoplankton to permit the inclusion of feeding rate in the model. The results generated show that, although simple in biological terms, the model gives a good approximation to the recorded growth of oysters in the sea. The model is intended to be sufficiently flexible to permit consideration of the effects of changes in the biological, physical and commercial environment of the oyster cultivation unit.

1.6 OBJECTIVES OF THE STUDY

The natural sciences have evolved into a hierarchical order, not in terms of importance, but as regards the evolution of ideas and their decreasing or increasing generality and complexity. As our knowledge of the complexity of natural systems improves so the need to collaborate with scientists of other disciplines and to perform interdisciplinary research becomes increasingly imperative. It is unrealistic to expect the management of natural resources to conform to artificial, academic discipline boundaries. Increasingly there is a need to appreciate and determine the economic and social value of research. Such an approach has long been practised in agriculture and forestry and it is logical to extend the technological-economic approach to the management of aquatic resources.

This study is an attempt to investigate the management of one marine resource, namely the oyster. To attempt a comprehensive investigation it has been necessary to draw on information from a wide range of sources. The time required to locate and gather such data and resources available made field experimentation impractical. The author has collated and appraised information regarding the biology and growth performance of oysters in order to derive an accurate growth model for both *O. edulis* and *C. gigas* grown in the sea under a range of conditions.

If an appraisal of the farming of oysters is to be attempted it is first necessary to understand those aspects of the species' biology which have a bearing on its culture, eg growth, reproduction, mortality. Furthermore, it must be appreciated how the isolation of oysters into a cultivation system affects the organism. Only conditions which increase natural yields are of benefit to the culturist. Estimates of yields under different culture techniques provide performance measures against which the predictions of the model may be measured.

Rough estimates of areas available for mariculture are important in determining the magnitude of the industry that can be developed. Detailed site surveys are required before any individual enterprise is established. However, desk surveys are a valuable means of identifying potential aquaculture sites. One aim of this study is to identify and where possible quantify a set of criteria upon which the selection of sites for oyster culture may be based. Environmental data for sites will be employed in the growth model to predict yields for individual sites.

The evolution of technical developments in oyster culture is well documented. The industry has reached the point where the technical feasibility of both bottom and suspended culture has been established on a commercial scale. However, this development has not progressed in a systematic way and it has been difficult in the past to accurately access the economics of oyster cultivation. This is partially due to an understandable desire to protect information regarding profitability but also reflects the scant attention which has been paid to the economics of production. All too often in aquaculture technical competence has not been matched by entrepreneurial skills. The author has attempted to ameliorate this situation. A comprehensive set of costs and statistics associated with oyster cultivation has been compiled for the year 1979. This information has subsequently been used to determine the likely rates of return from such investments. The utilisation of the derived growth model and capital investment techniques has permitted the development of a method to establish the profitability of any potential investment in oyster cultivation. Moreover this study will demonstrate the value of sensitivity analysis in establishing the magnitude of change in return on investment brought about by variation in biological, physical or economic variables. This technique permits the investor to establish the sensitivity of the investment to such changes prior to any capital outlay. An awareness of such implications will nurture better decision-making by management.

Any product requires a market and this study would be incomplete without a discussion of the market for shellfish and oysters in particular. The principle market for oysters remains the sale of Flat Oysters for consumption in the half-shell. The author presents information which demonstrates the seasonal nature of this trade and the relative importance of the major fisheries. The potential of cultivated oysters to exploit this and new markets is discussed and proposals made regarding a marketing and pricing policy for these oysters.

This investigation assumes that the investor has selected aquaculture as an appropriate investment from the opportunities open to him. From the range of options available the investor must select the system which best suits his particular situation and his operating philosophy. He must appreciate the level of risk involved, the factors contributing to it, and how best to minimise it. This study provides the necessary information upon which such judgements may be based. The derived model and illustrations of the investment appraisal techniques provide the researcher or investor with adequate tools to access the viability of individual proposals. Finally it may be said that the successful application of these techniques to oyster cultivation may encourage their more widespread use in aquaculture as a whole.

Chapter 2

THE BIOLOGY OF THE OYSTER

2.1 DESCRIPTION AND DISTRIBUTION

The oysters belong to a large and highly successful class of organisms called the Bivalve molluscs. Characteristically the body is laterally compressed between two valves connected above by an elastic ligament, all forming the shell. Anatomical differences divide oysters into two groups or genera; the Flat oysters of the genus Ostrea and the Cupped oysters of the genus Crassostrea. Both genera contain species which are commercially exploited in the British Isles (plate 2.1).

2.1.1 Genus Ostrea

The genus Ostrea occurs in all oceans from the tropics to the arctic and antarctic. Species of this genera thrive in clear, usually more offshore and so more saline water. They normally grow naturally in extensive colonies or beds in shallow water where they may be partially or wholly exposed at low water of spring tides.

The European Flat Oyster (*Ostrea edulis,* Linnaeus) occurs from 65° North in Norway as far south as Morocco. It is found throughout the Mediterranean and penetrates the Black Sea as far as the Crimea. There is some evidence for the existence of distinct physiological races through its distribution each having a different spawning temperature. The only other commercially important species of this genus is *Ostrea lurida*, the Native Pacific Oyster of the United States.

Description: Genus Ostrea

Flat oyster with the left valve not deeply cupped and more or less circular in outline, the muscle scar near the centre and not coloured; no promyal chamber; eggs relatively large, up to 1,000,000 and incubated in the inhalent chamber; larval shell (prodissoconch) with unequal valves having two teeth at each end of the hinge plate (provinculum) although auterior pair may be reduced, ligament in the hinge plate. Yonge (1960).

2.1.2 Genus Crassostrea

The genus Crassostrea contains a large number of species, many of which are commercially exploited. The distribution of this genus is restricted to lower latitudes than that of the genus Ostrea. Crassostrea is generally more functionally adaptable and can withstand wide and sudden changes in salinity and more turbid water. The genus is able to fully exploit the richer food supplies and greater protection offered by estuaries, creeks and other inshore waters.

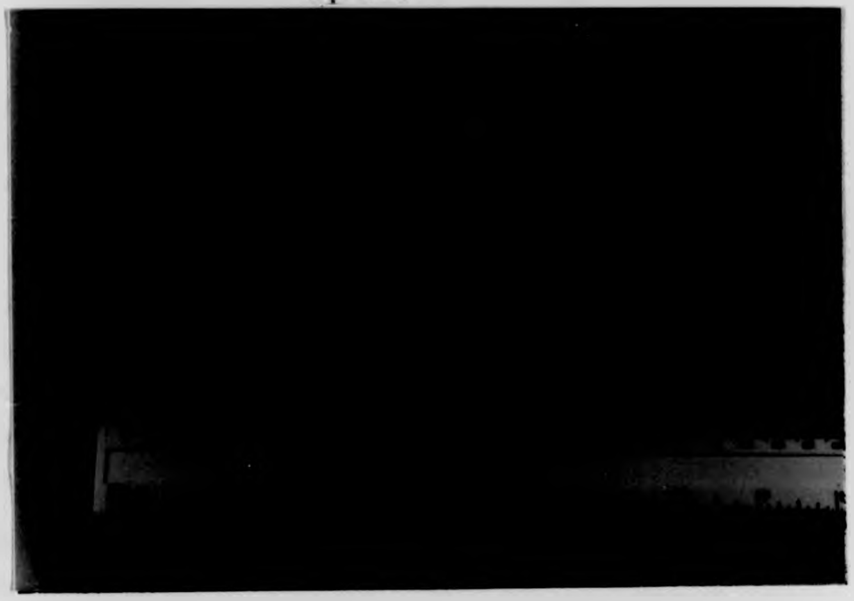
Commercial interest in the United Kingdom has centred on three species. The American Oyster (*Crassostrea virginica*, Gmelin), the Portuguese Oyster (*C. angulata*,Lamarcle) and the Japanese or Pacific Oyster (*C. gigas*, Thumberg). Importations of the first two species were responsible for the introduction of a number of oyster pests and disease. Emphasis, at present, is directed towards the cultivation of the fast growing Pacific Oyster.

Description: Genus Crassostrea

Oyster with the left valve deeply cupped, elongated, typically larger than Ostrea, muscle scar nearer to shell margin than to the hinge, usually deeply pigmented. A promyal chamber is present providing an additional passage for the exhalent current on the right side. Eggs small, may exceed 50,000,000 in number, not incubated; larval shell somewhat asymetrical and with uneven valves having two teeth at each end of the hinge plate, ligament away from this. Yonge (ibid).

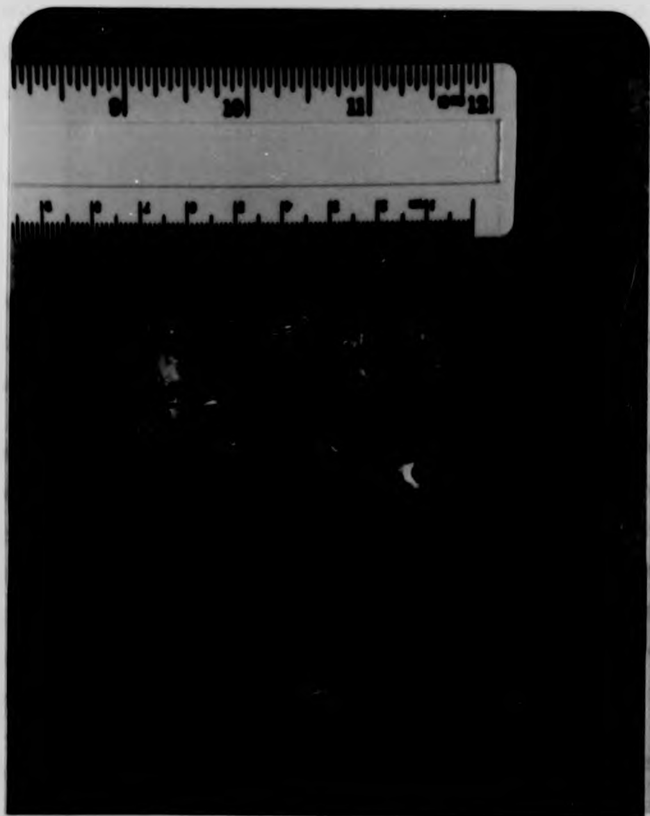
Plate 2.1

Top view



A Crassostrea gigas

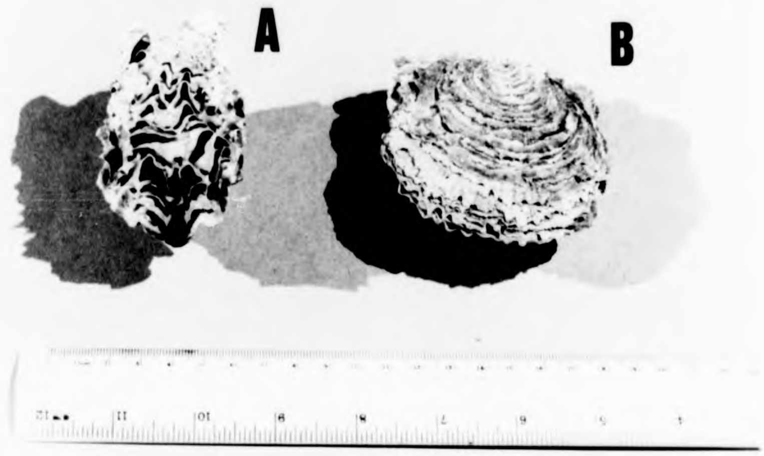
B Ostrea edulis



Side view

Plate 2.1

Top view



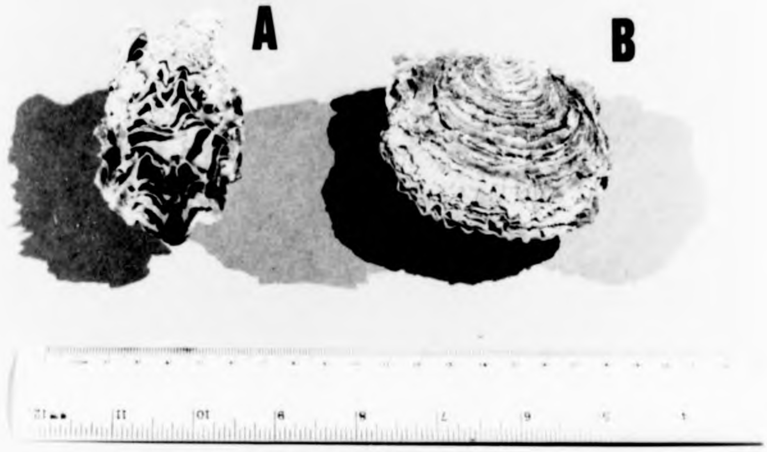
A Crassostrea gigas

B Ostrea edulis

Side view

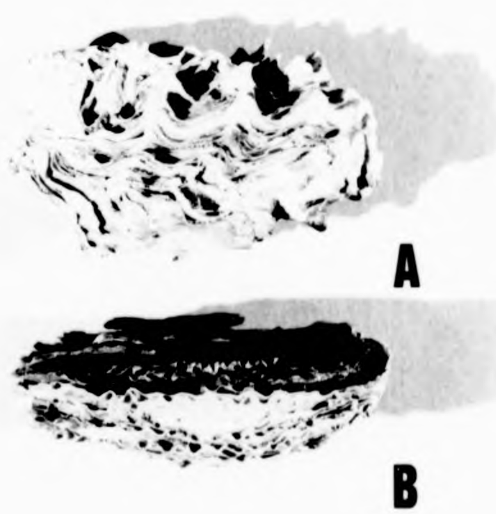
Plate 2.1

Top view



A Crassostrea gigas

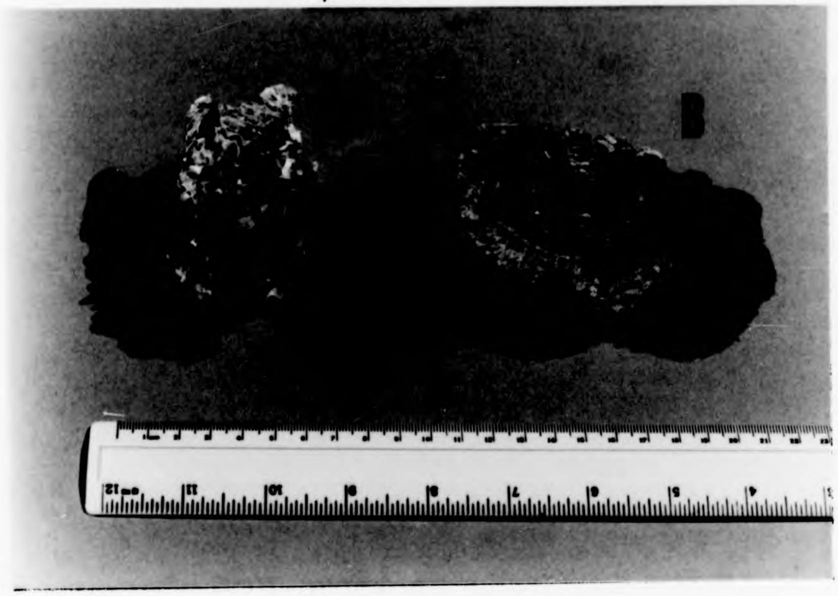
B Ostrea edulis



Side view

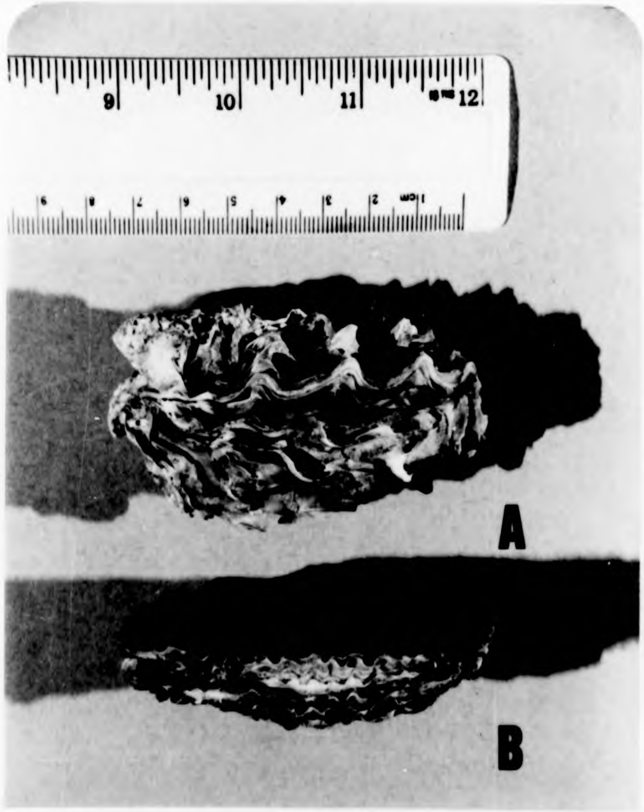
Plate 2.1

Top view



A *Crassostrea gigas*

B *Ostrea edulis*



Side view

2.2 MORPHOLOGY

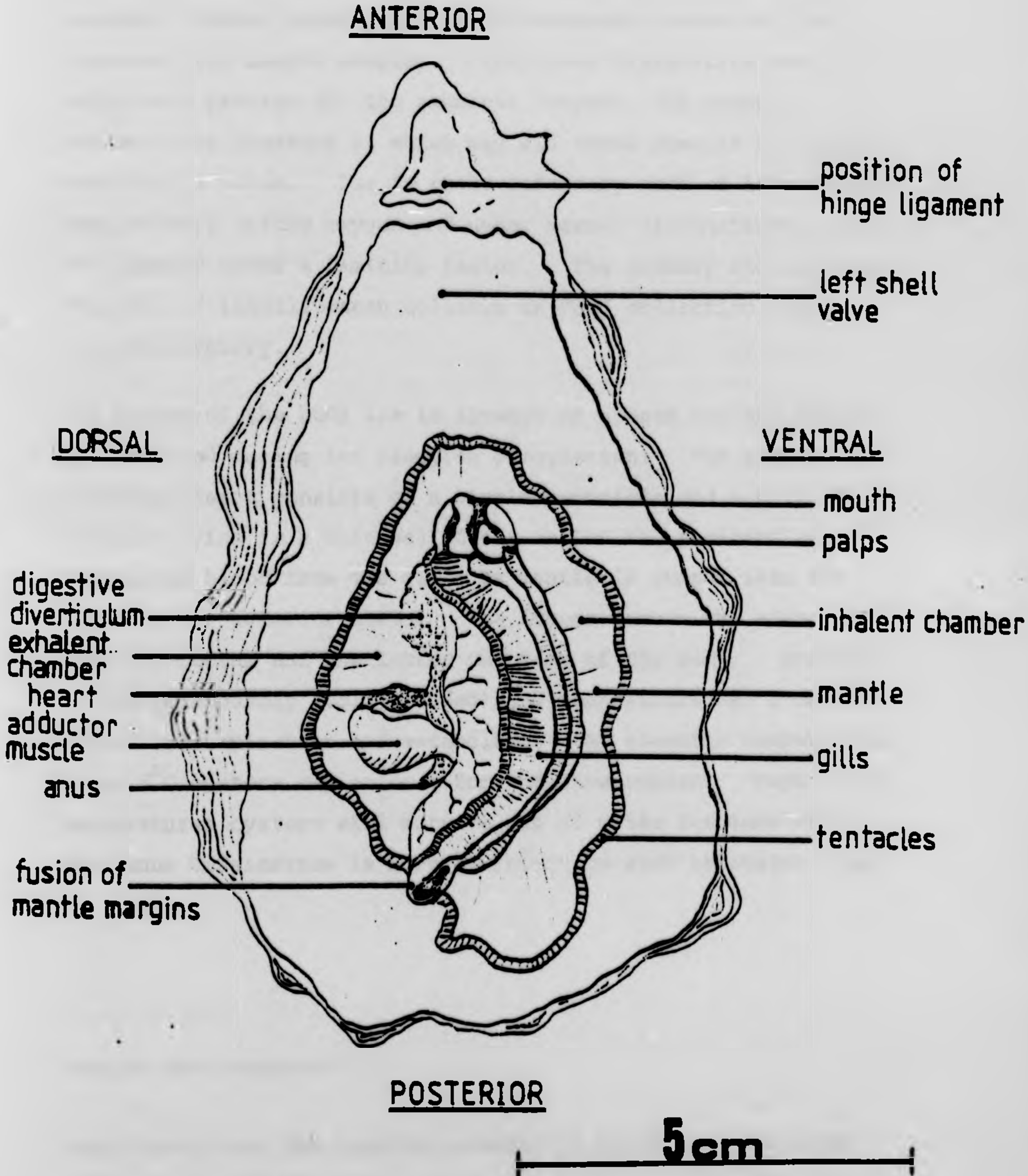
The oyster shell is made of conchyolin (horny, organic material) with much calcareous material in the valves but not in the dorsal ligament. The shell is formed by the outer fold of the mantle margin. Irregular growth lines on the shell surface represent successive "shoots" by which the shell receives sudden, initially very thin, marginal additions. Shell growth in both genera is much at the mercy of the environment and as a result very variable. Typically oysters are cemented by their left valve to the substrate but there is no evidence that individuals cemented by the right valve or in the vertical position have any growth disadvantage. The main morphological features of the Pacific Oyster, *C. gigas* are illustrated in Figure 2.1.

Firmly attached to the inside of both shell valves is the central adductor muscle (the monomyarian condition). The adductor muscle acts antagonistically to the elasticity of the ligament and controls shell gape. It is a characteristic feature of dead or sick bivalves that they gape widely. The adductor muscle is in two parts. The "quick" portion is composed of striated muscle fibres and responsible for the rapid clapping of the valves used to expel pseudofaeces and the products of the reproductive system. The "catch" muscle portion is composed of smooth muscle fibres and controls prolonged, sustained closure of the shell at the cost of only a small expenditure of energy. This is an important adaption when exposed to air or attacked by predators. Species of the genus Crassostrea have a high quick:catch muscle ratio compared to Ostrea, a feature which permits the more efficient expulsion of waste.

Dorsal to the adductor muscle and ventral to the ligament lie the stomach, intestine, heart and kidneys. In oysters of poor quality or individuals which have recently spawned this area is brown in colour. The gonad has a simple form in both sexes and consists of an area of branching tubules covering the outer surface of the digestive gland. When ripe the creamy colour of the gonad obscures the brown colour of the digestive gland.

A foot and byssus gland make only a transitory appearance in the

Figure 2.1 The main morphological features of *Crassostrea gigas*



early larvae. The adult is sessile and in consequence expends little energy on locomotion.

The large crescent shaped gills or ctenidia lie in the large inhalent chamber separated from the exhalent chamber by the fusion of the mantle margins. The genus Crassostrea has an additional passage for the exhalent current, the promyal chamber, the presence of which may aid these species to tolerate more turbid water. Due to their sedentary mode of life oysters require very little oxygen and under normal circumstances oxygen is probably never a limiting factor. The primary role of the ctenidia in lamellibranch molluscs is food collection rather than respiratory.

The organs of the body lie in sinuses or spaces and are bathed by the blood during its sluggish circulation. The simple molluscan heart consists of a single ventricle and a pair of auricles lying in a thin-walled sac called the pericardium. Oxygenated blood from the gills or mantle is pumped into the posterior or anterior aorta. The former serves the adductor, anus and rectum and the latter the rest of the body. Oysters are poikilothermic (cold-blooded) and temperature has a marked effect on respiration and metabolism. At seawater temperatures below 5°C oysters may enter a form of hibernation. Kept at low temperatures oysters will survive out of water for some weeks. The genus Crassostrea is more resistant to such treatment than *O. edulis*.

2.3 FEEDING AND DIGESTION

Water drawn into the inhalent chamber is moved into the water tubes of the gills by the action of countless, whip-like cilia on the gill surfaces. From the water tubes the filtered water passes to the exhalent chamber and then out of the mantle cavity. There are three basic types of cilia on the gill filaments. The lateral cilia which by their beating push particles towards the mouth. There are also cleaning frontal cilia and on the exposed edges of the filaments latero-frontal cilia which sieve particles from the water current and pass them onto the frontal surfaces. Here particles are enveloped in mucus, aggregated and passed along ciliary tracts to the base or the free margins of the demibranchs (half-gills). At these points are grooves along which particles pass for further sorting on the labial palps then onto the mouth. Waste particles are moved by cilia to the mantle margin. When sufficient waste has accumulated in this manner it is expelled as pseudofaeces.

Filtration may remove up to 75% of the particulate matter present in the water and efficiently removes particles of sizes down to 2 - 3 μm. The exact composition of oysters' natural diet is unknown but in hatcheries unicellular algae cultures have proved to be acceptable (Walne, 1970a). In the sea oysters may be able to utilise certain dissolved materials from the environment (Jorgensen, 1976). It is not known whether the selection of particles on the gills is purely on size or whether the gills are more discriminatory rejecting non-nutritious matter.

Digestion of ingested particles occurs in the stomach, digestive tubules or through non-respiratory blood pigments imigrating into the stomach cavity. These pigments act in a phaegocytic manner engulfing particles then moving back through the stomach epithelium to the blood stream. The rest of the digestive system is concerned with faecal pellet formation.

2.4 REPRODUCTION

Juvenile *O. edulis* reach sexual maturity in Britain in the summer following settlement. The gonad develops as the male producing sperm then after spawning the oyster changes in to a functional female., a reproductive behaviour referred to as protandric alternating hermaphrodism. Further alternations of sex occur throughout the life of the oyster. The two states occasionally overlap during the transition period but self-fertilisation is not thought to occur. The sex change female to male is the less complicated of the two and takes a few days whereas the male to female alternation may take a few weeks.

In Britain spawning begins in the summer when seawater temperatures exceed 15^{o}C but for successful incubation and larval growth higher temperatures are required. Spawning generally occurs twice in a season, once as each sex but in warmer latitudes several spawnings may occur in a season. Artificial stimuli of either chemical, electrical or thermal nature may be employed to initiate spawning. Thermal and chemical stimuli in particular are widely used in commercial shellfish hatcheries. Functional males discharge sperm through the genital pores into the exhalent current. Eggs remain in the inhalent chamber for a number of weeks. Here they are fertilised by sperm drawn in with the inhalent current and develop to fully shelled larvae before they are expelled to complete their development in the sea. The incubatory period for the larvae of *O. edulis* is between one to two weeks depending on temperature. The presence of developing larvae on the gills makes the brooding *O. edulis* unpalatable. As the larvae develop they darken due to pigmentation and the adult appearance passes through stages referred to as 'whitesick', 'greysick', and 'blacksick'. Larvae are released to begin the pelagic phase at a size of 170 - 190 μm (Walne, 1974).

The genus Crassostrea is different. Initially as with *O. edulis* all oysters attain sexual maturity as functional males but then the population divides into those that remain as males and those that become females. Sex reversal in the Cupped Oyster takes place in winter. The animal retains the same sex throughout the spawning season. A high metabolic rate favoured by good feeding promotes the formation of ovaries; low metabolic rate is associated with the male condition. Crassostrea species exhibit the more primative female sexual development in which fertilisation and development of larvae is non-incubatory. Species of this genus are not indigenous to the British Isles and occurrences of natural spatfalls are extremely rare (Askew, 1972). The cultivation of cupped oysters is totally dependent on hatchery reared spat. Non-incubatory species of oyster produce smaller but larger quantities of eggs than *O. edulis*.

In both genera the most prominent feature of the pelagic larvae is the velum. This lobe of tissue bears cilia and acts both as the organ of feeding and locomotion. This phase sees the development of the larval shell or prodissoconch, rudimentary heart, adductor muscles and other organs. The larvae remains motile for one to three weeks depending on ambient temperatures. Each time the developing larvae comes into contact with a hard substrate exploratory behaviour begins with the feet. If the site proves unsuitable for settlement the foot is withdrawn and the larvae swims off. The ability to delay settlement improves the chances of successful settlement to approximately one in ten thousand. The settling oyster larvae are called spat and the process of settlement spatfall.

If a suitable substrate is found the left valve is cemented to the surface by a drop of cement extruded from the byssus gland at the base of the foot. Metamorphosis from the larval to the basic adult form occurs within forty eight hours. In the case of *O. edulis* the fully formed spat measures 1 - 2 mm and has acquired all the adult features within three to four days of spatfall.

It is notable that hatchery reared larvae grow faster than naturally occurring larvae, reach maturity earlier and attain a larger size. For commercial purposes the spat should be detached from its settlement surface before it exceeds two or three centimetres in size, otherwise the oyster will grow excessively flattened or if overcrowded conditions exist it will be distorted.

2.5 OYSTER PESTS AND DISEASE

There are a number of species which actively prey on oysters or compete with them for food and space. Predation is primarily a problem on oyster beds and layings where protection is minimised.

The most serious pest on oyster grounds are marine gastropods, known as drills or whelks. The native sting drill, *Ocenebra erinacea* was estimated to kill on average 20% of the oyster population on one ground in the western Solent (Key, 1977a). The introduced American Oyster Drill, *Unosalpinx cinerea* and occasionally the Dog Whelk, *Nucella lapillus* also attack oysters.

Drills grow to about 3 cm, the native species being slightly larger than the American Drill. The mode of feeding is similar in both species. The proboscis is extended and the radula armed with hardened teeth is used to drill a hole through the oyster shell. When the hole is complete the proboscis is used to scoop out the living flesh. Oyster drills exhibit a marked preference for the thin shelled spat rather than fully grown oysters.

The distribution of *Ocenebra erinacea* is now restricted to the southwest of England and Wales. The species was exterminated in the rest of the country by the severe winters of 1939 - 40 and 1946 - 47. The American Oyster Drill has no pelagic larval phase in its life history and this has served to limit its distribution to the areas of the southeast of England where it was first introduced.

The other major predators are found throughout the British Isles. The common starfish, *Asterias rubens* is often taken in large numbers off oyster grounds. Dredging and dumping on land are the only certain ways to remove starfish. The ubiquitous shore crab, *Carcinus maenas* will break the shell margin of small oysters and then pick out the flesh with the chelae. Parsons (1974) recorded high mortalities of seed oysters apparently due to *C. maenas* but juvenile oysters greater than 0.5 grammes were not readily attacked. Cultivation of seed oysters in trays, bags or fenced enclosures effectively excludes predators.

The Slipper Limpet, *Crepidula fornicata* was introduced into this country circa 1880 and is now a serious competitor of the oyster. The species has spread over many oyster grounds in England and may occur in high densities. Past surveys on oyster beds in Essex have revealed densities of this pest as high as 24 kg per square metre (Hancock, 1974). Individuals aggregate to form spirally curving chains of up to thirty limpets. They are filter feeders so directly compete with oysters for food as well as for suitable substrates. The only effective method of control is to physically remove the pest from the area and either crush or dump the limpets on land.

All larvae which settle at the same time and on the same site as oyster larvae are potential competitors. The asidian *Axidiella aspersa* was found to compete with spat for settlement on spat collectors in some Scottish sea lochs (Millar, 1961). In intertidal tray culture fouling organisms may reduce the growth of seed oysters by restricting water flow through the trays. Large mesh sizes, regular cleaning and good husbandry are the most effective methods of control.

Epizooitic organisms which live on the oyster shell may damage the oyster itself and affect appearance and hence marketability. The sponge, *Clione celata* bores into the surface of the oyster shell to gain protection. Emanciation and death of the oyster may result as it attempts to repair the shell with layers of conchyolin. Infestation may be common locally and is particularly damaging to older oysters. The sponge is intolerant of low salinity and bathing the oyster in freshwater may arrest the early stages of invasion.

Two species of bristleworm may infest the oyster shell. The worm *Polydora ciliata* grows to two to three centimetres and bores into the shell undermining its structure. A second species *P. hoplura* is larger and inserts itself between the shell and mantle. In response the oyster forms a marginal blister to which further inward extensions may be added as the worm grows. In both cases the oyster must divert energy from growth to replace the shell lost by the action of the worms. The presence of epizooites reduces the value of the oyster and may weaken the animal.

Heavy mortalities due to outbreaks of disease have occurred sporadically throughout the history of modern oyster cultivation. In 1920 - 21 the European population of *O. edulis* was decimated by a minute flagellate protozoan, *Hexamita* spp. (Mackin et al, 1952). On the Continent shell disease or 'meladie du pied' is widespread. The disease is caused by a fungus, *Althornia crouchii* which attacks the thin areas of the shell margin. The fungus lives on the organic matrix of conchyolin and never penetrates the living Tissue (Alderman, 1969). Infection is in two stages. An initial stage when tiny, white spots appear on the inside of the shell. This gives way to green or brown rubber-like warts of conchyolin within which the fungal mycelia can be seen. The fungus is obligatory marine and requires warm water for growth. The distribution of the disease in the British Isles is restricted to isolated areas on the south and south-east coast of England.

More recently an epizooite disease referred to as Aber disease has been reported as causing mass mortalities of flat oysters in France (Alderman, 1974). The disease is caused by a pathogen which disrupts the lining of the oyster digestive gland. Infection usually results in the death of the oyster. Strict controls on the introduction and deposit of molluscan shellfish have been successful in preventing the establishment of the disease in the United Kingdom.

The cultivation of oysters is particularly open to the possibility of attack by disease. High stocking densities and regular handling provide conditions where infection may spread rapidly. The science of aquatic pathology is still very much in its infancy. Often the symptoms but not the infecting agent of the disease are known. Under such circumstances the maintenance of a high standard of husbandry is vital.

Chapter 3

OYSTER FISHERIES AND CULTIVATION

3.1 PAST STATUS AND DECLINE OF FISHERIES

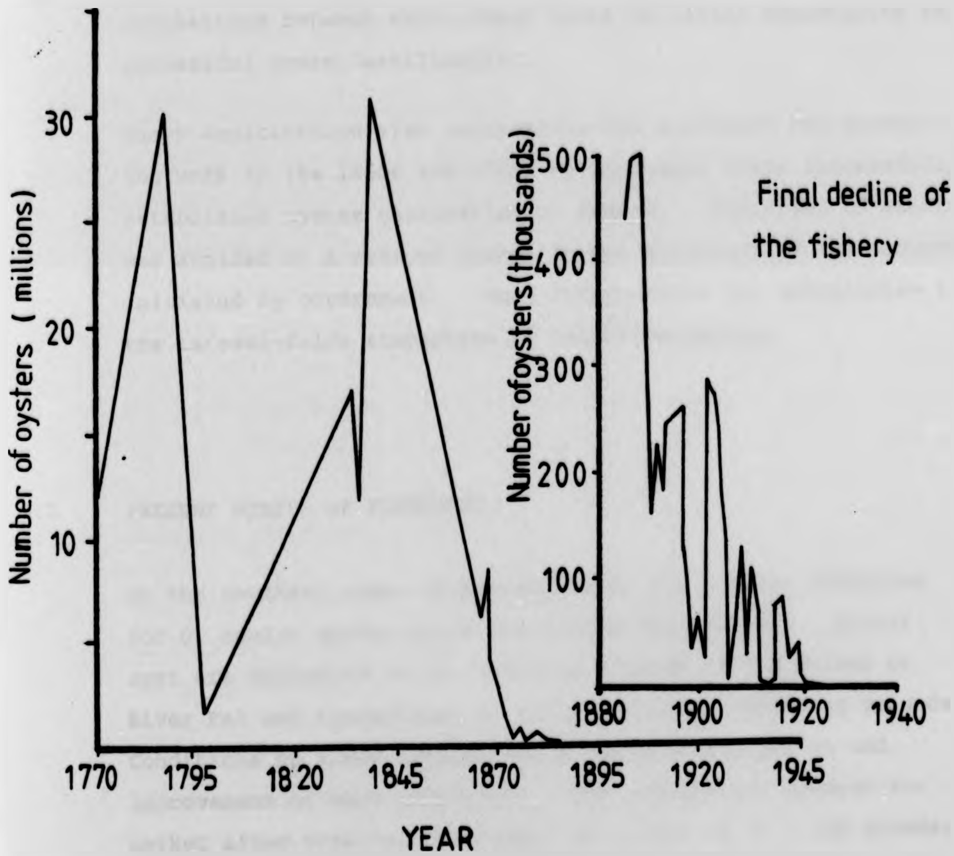
The Native Flat Oyster (*O. edulis*) has long been prized for its delicate flavour. The Roman, Sallust, wrote in 50 BC "Poor Britons - there is some good in them after all - they produce an oyster". (Yonge, ibid).

Large oyster fisheries were supported by the extensive, natural beds on the Essex coast, Thames Estuary, Firth of Forth and many other areas. In 1864 at Billingsgate Market alone 495 million oysters are recorded as being sold. Such was their abundance that oysters were a staple food of the poor.

In the latter half of the nineteenth century stocks declined drastically as a result of more intensive fishing and the opening up of inland markets made possible by the advent of rail transport. Despite the introduction of legislation, aimed at conservation in 1868, the decline was such that by 1920 many former beds including the Firth of Forth were exhausted (Figure 3.1). Commercial oyster fishing in Scotland continued until the closure of the Loch Ryan grounds in 1954 (Millar, 1961). By 1960 the vast oyster harvests of the past had shrunk to 8.5 million oysters of which perhaps one-third were relaid Portuguese Oysters (*C. angulata*).

Several reasons have been suggested to account for the denudation of the British oyster beds including overfishing, disease, severe weather and inadequate spatfalls. All may have contributed to some extent but in the Firth of Forth, which is the best documented instance, there is no doubt that overfishing was the prime cause (Fulton, 1896; Millar, ibid;. Yonge, 1970). Large areas of the former beds with suitable substrate for oyster settlement still remain. However, the relaying of

Figure 3.1 <u>The Decline in Landings from the Firth of Forth Oyster Fishery</u>



source Miller (1961)

oysters would be prohibitive in terms of costs and highly risky due to the low incidences of successful spatfall at the ambient seawater temperatures.

Overfishing in the past in itself does not explain why grounds where fishing ceased before extinction have not recovered. Gross and Smyth (1946) postulated that overfishing may reduce the genetic variability present in an oyster bed. Reduction of the gene pool would make the oysters less able to adapt to changes in the environment. This trend towards genetic uniformity would be reinforced by the isolation of small oyster populations between which there would be little opportunity for successful cross-fertilisation.

Heavy exploitation also occurred on the Continent but pioneering work in the 1850s and 1860s by Professor Coste successfully established oyster cultivation in France. Depletion of stocks was avoided by a radical change in the structure of the industry initiated by government. Such intervention was unthinkable in the laissez-faire atmosphere of Victorian Britain.

3.2 PRESENT STATUS OF FISHERIES

On the southern coast of England there still exist fisheries for *O. edulis* operating in the traditional manner. Oyster spat are collected on the spatting grounds of the Solent or River Fal and transferred in early Spring to fattening grounds. Conditions on these grounds are favourable for growth and improvement of meat condition. The oysters are dredged for market after three or four years at a size of 45 - 100 grammes.

Oyster dredgers are up to two metres in size and triangular in outline. A collection bag is supported on the upper surface of the dredge. A minimum mesh or ring size of 63 mm (2½") is employed. It is estimated that vessels using such dredges took an average of 0.3 tonnes oysters per week in the 1977 - 1978 season (Key and Davidson, ibid).

On the River Fal fishery only vessels powered by sail are permitted. Fishing is carried out in shallow draught boats of 6.9 metres length. The crews hand-dredge as the boats drift down tide and then sail upstream for the next sweep over the ground.

Until recently the Solent was not a significant oyster fishery. In the early 1970s Stanswood Bay received a considerable natural settlement of oysters (Key, 1972, 1974). Regular spatfalls have extended the grounds such that annual landings have reached 650 - 850 tonnes with a first sale value of approximately £1 million. The emergence of this fishery has given a considerable impetus to the oyster industry. In 1972 there were seventeen boats on the Solent fishery. Six years later the number had risen to 450 vessels. Solent oysters are fast growing and are harvested after three years at the relatively small size of 50 grammes. There is a substantial export trade to France reversing the trade of earlier years (Chapter 8). Recruitment on these beds is good as are the prospects for the fishery, if properly managed. The introduction of a licencing system, a closed season from 14 May to 4 August on most grounds and the provision of bivalve shells for spat settlement (clutch) have all proved to be valuable conservation measures.

The only self-perpetuating oyster ground in Scotland is that in Loch Ryan where a good spat settlement in 1975 produced a large increase in stock. The fishery has subsequently been re-opened by the Colchester Oyster Fishery Limited.

The revived fisheries are unable to satisfy the current demand for oysters in the United Kingdom. Dredging is expensive, non-selective and dependent on regular spatfalls and good management of grounds. A ready market exists for any entrepreneur who can cultivate oysters in commercial acceptable quantities.

3.3 HATCHERIES

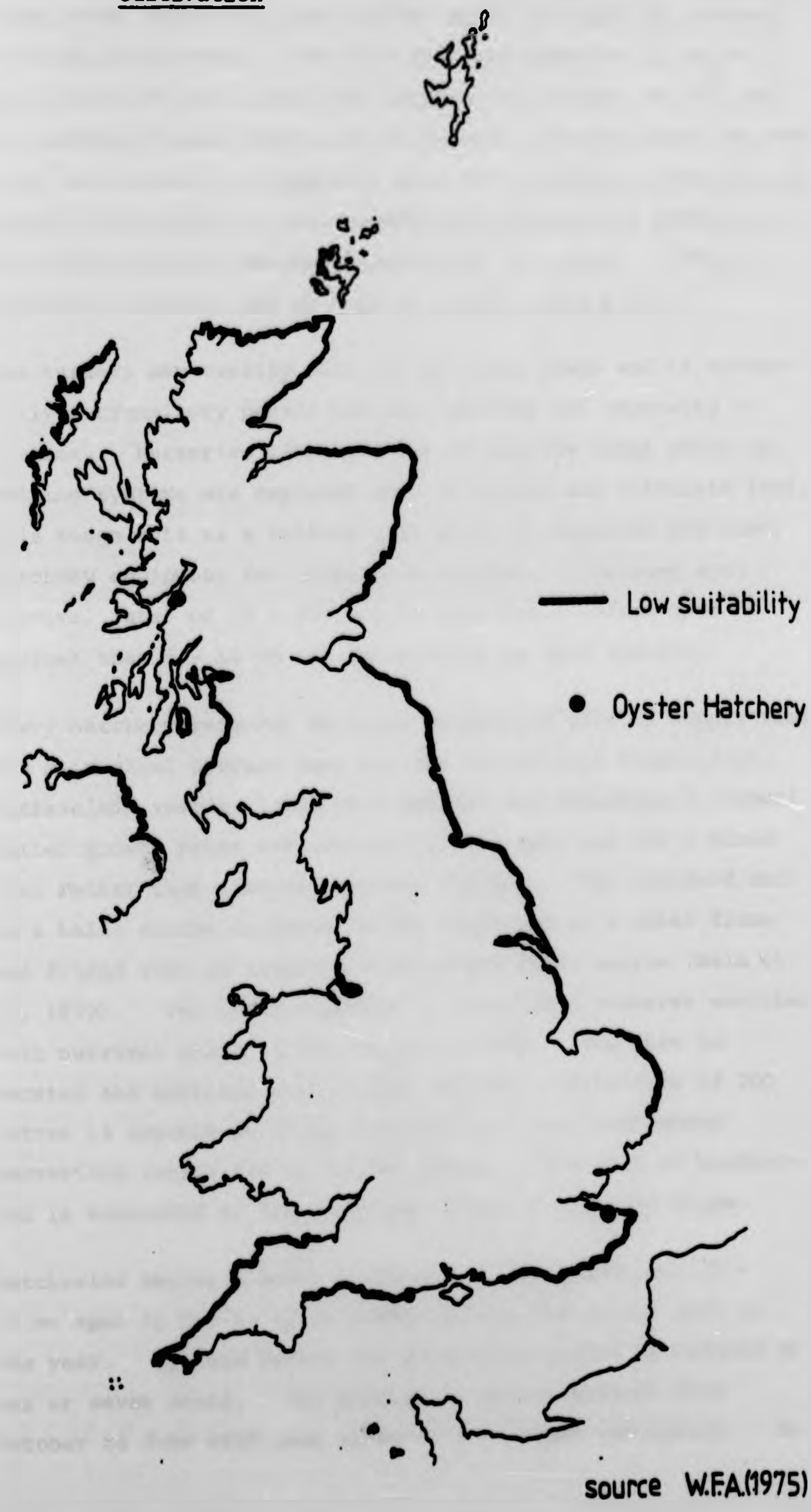
The irregular supply of oyster spat has always been a major constraint on the operations of the industry. In the 1960s the MAFF undertook to develop routine, commercially feasible techniques for the conditioning, spawning, rearing and holding of oysters. The success of this work is well documented (Walne, 1970a, 1974; WFA, 1976). At present there are ~~two~~ commercial hatcheries supplying spat to the industry (Figure 3.2). Operating procedures differ between hatcheries but there are five basic stages of production (O'Sullivan, 1976).

(i) Adult brood stock holding unit
(ii) Brood stock conditioning and spawning unit
(iii) Larvae rearing unit
(iv) Post settlement ongrowing unit
(v) Nursery.

A stock of 100 mature oysters may be held in a 250 litre holding unit at a seawater temperature of 10°C. Seawater is aerated and recirculated at a flow of 4 litres/hour. When required the brood stock is transferred to a conditioning unit where the recirculated seawater temperature is maintained at 20°C. The oysters are maintained in shallow trays for up to six weeks to ensure that they are in prime condition. The feed throughout the hatchery is cultured phytoplankton supplied at a concentration of 100 algal cells/µl.

O. edulis will spawn naturally when seawater temperatures exceed 16°C but *C. gigas* requires both thermal and chemical stimuli. Spawning is induced by alternating seawater temperature from ambient to 28 - 30°C at 30 minute intervals and by the addition of sperm to trigger the release of eggs from females. Fertilised eggs are collected, sieved, washed and transferred to larvae rearing bins. These bins are maintained at 25°C for the two to three weeks of the free-swimming larval development. The risk of mortality at the larval phase is high. Hygiene, handling and aeration must all be strictly controlled.

Figure 3.2 The Distribution of Shellfish Hatcheries and Areas of the United Kingdom coastline suitable for Shellfish Cultivation



The development of a larval eye spot and foot is the signal for the introduction of spat collectors. The settling process takes some twenty-four hours after which the spat are removed from the collectors. The free spat are grown-on in trays in recirculation units where the temperature is kept at 22°C and the feeding regime maintained as before. In the trays the seawater environment is gradually altered to condition the spat to natural conditions. This conditioning period may extend over six weeks to three months depending on the season. Stock is regularly regraded and thinned as growth takes place.

The nursery may overlap with the previous stage and is essentially a transitory period between hatchery and ongrowing in the sea. Nurseries often consist of outside tanks where upwelling systems are employed both to aerate and circulate food. This stage acts as a holding unit prior to dispatch and frees hatchery equipment for successive batches. Nursery spat survival rates of 15 - 30% may be expected. Often spat of greater than 5 - 10 mm are referred to as seed oysters.

Every hatchery requires an algal production unit to supply food. The main algal species used are the unicellular flagellates, *Tetraselmis suecia*, *Isochrysis galbana* and *Monochrysis lutheri*. Better growth rates are achieved if the spat are fed a mixed diet rather than a single species culture. The standard unit is a tall, narrow cylinder or bag supported in a metal frame and fitted with an internal fluorescent light source (Helm et al, 1979). The culture medium of autoclaved seawater enriched with nutrient salts is maintained at 18°C. The unit is aerated and enriched with carbon dioxide. A culture of 200 litres is capable of being operated on a semi-continuous harvesting regime for up to two months. The cost of production is estimated at 3.0 pence per litre of cultured algae.

Hatcheries employ a batch production system producing 10 - 15 mm spat in two to three months during the colder part of the year. By late Spring the production period is reduced to six or seven weeks. The production season extends from October to June with peak sales in the Autumn and Spring. In view of the considerable production lead time hatcheries offer discounts for early ordering. There are substantial advantages to be realised from the use of several small production units both in handling and the ability to carry a large number of grades over a wide range of species. The hatchery is essentially a capital intensive unit with its major operating costs identifiable as heating and lighting. In this study hatcheries are only considered as exogenous suppliers of spat and consideration of hatchery economics is outwith its scope.

3.4 OYSTER CULTIVATION

The oyster is probably the most thoroughly domesticated of all marine animals. As early as the first century BC oyster culture was practiced by Romans in lagoons or ostriaria in Lago Lucrino, north of Naples. Modern oyster culture began in France in the nineteenth century. Production is centred on the Bay of Arcachon, Chareute Maritime and Morbidhan district of southern Britanny. All oysters are cultured intertidally, the Morbidhan district produces *O. edulis* and the two other regions *C. gigas*. Natural spatfalls are collected and the oysters grown to 50 - 60 grammes in fenced, intertidal 'parcs'. Then the oysters are transferred to 'claires' for fattening. These are clay-lined pits where blooms of the diatom, *Navicula ostrearia* are encouraged to flavour the oysters and give them a green hue (spéciales de claires) prior to marketing (Figure 3.3). The production cycle is approximately eighteen months. With a production of over 100,000 tonnes in 1979 France remains the largest oyster producer in Europe (Table 3.1).

The French system of cultivation is not very sophisticated. It is heavily dependent on natural spatfalls, algal blooms and is very labour intensive. There is little opportunity for mechanisation on the extensive intertidal flats required for this form of cultivation. The labour requirement and dependence on spatfall rule out commercial cultivation of this type in the United Kingdom. The cost of labour would be prohibitive.

Figure 3.3 The culture of *Crassostrea gigas* in the Charente Maritime region of France

July - August: put out collectors

↓

March - April: remove shell strings and relay or sell spat.

↓

Leave for one year

↓

Harvest in Spring
(Autumn of planting year if grow well)

↓

Separate bunched oysters
(10 - 30 Kg/1,000 oysters)

↓

Supplement with oysters from other regions → Demi-élèvage stage:
plant out in intertidal parcs at 10 Kg/m^2
(1 ton/acre)

↓

Harvest at 50 - 60 Kg/1,000 in Autumn of same year

↓

Clean and grade at base

↓

Lay in claires for further fattening

↓

Harvest in September:
Spéciales de claires

↓

Plant out next crop in the claires in September:
Densely laid (600 Kg/claire) to thicken shell rather than fatten oysters

↓

Harvest November - December: peak of season
'Fines de claires'

↓

Period in a degorgeoir:
to purge the oysters of pseudofaeces

↓

Hold in storage pits until go to market.

After Korringa (1976)

Table 3.1 World oyster landings by Country in 1979

Country	Landings (metric tonnes)	Species Key
United States	290,157	C,G,H
Japan	205,509	G
Korean Republic	171,118	G
France	105,919	A,F
Mexico	38,554	E,H
Other Nations*	19,920	G
Thailand	11,703	J
New Zealand	10,131	D,J
Australia	8,123	J
Canada	3,564	G,H
Cuba	2,700	I
Netherlands	1,075	A
Sierra Leone	950	J
Philippines	799	J
United Kingdom	680	A,F,J
Brazil	404	J
Indonesia	375	J
Ireland	332	A
South Africa	275	G,J
Chile	213	B
All other countries	274	A,E,F,I,J
TOTAL	872,780	

* No further classification of *C. gigas* catch given.

Species Key

A *Ostrea edulis*
B *Ostrea chilensis*
C *Ostrea lurida*
D *Ostrea lutaria*
E *Ostrea spp.*
F *Crassostrea angulata*
G *Crassostrea gigas*
H *Crassostrea virginica*
I *Crassostrea rhizophorae*
J *Crassostrea spp.*

Source: FAO (1980)

Table 3.2 World oyster landings by Species, 1976 - 1979

SPECIES		NOMINAL CATCH IN METRIC TONNES				FISHING REGION
Common name	Generic name	1976	1977	1978	1979	
European Flat Oyster	*O. edulis*	9,114	11,531	6,419	7,657	Europe
Chilean Flat Oyster	*O. chilensis*	57	73	74	213	Chile
Olympia Flat Oyster	*O. lurida*	124	75	75	74	North America
New Zealand Dredge Oyster	*O. lutaria*	9,578	10,014	8,392	8,476	New Zealand
Other Flat Oysters	*Ostrea spp.*	1,277	2,368	1,741	2,498	Worldwide
Portuguese Cupped Oyster	*C. angulata*	85,863	105,012	91,834	100,542	Europe
Pacific Cupped Oyster	*C. gigas*	432,009	415,227	435,059	422,674	Worldwide
American Cupped Oyster	*C. virginica*	343,967	283,801	325,398	303,742	North America
Mangrove Cupped Oyster	*C. rhizophorae*	2,597	2,350	2,943	2,705	Central America
Other Cupped Oysters	*Crassostrea spp.*	19,386	29,232	27,508	24,199	Asia
TOTAL CATCH		903,972	859,683	899,443	872,780	

Source: FAO (1980)

In the British Isles oyster hatcheries have permitted the exploitation of sites where conditions are suitable for growth but not necessarily for successful spatfalls. The predominant method of culture is intertidal tray systems producing primarily the fast growing Pacific Oyster (*C. gigas*). Official statistics often omit or fail to separate production of cultured oysters from oyster fishery landings. However it is estimated that the production of cultured oysters in 1979 was 300 tonnes. Combined with fishery landings this yields a total catch of approximately 1,000 tonnes. This level of harvesting is insignificant when compared to relevant statistics for world oyster catches (Tables 3.1 and 3.2).

[illegible]

Once relaid in the sea any of several systems of intertidal or suspended culture may be employed for ongrowing. At each site the capabilities of the system must be weighed against the cost in terms of both equipment and labour. The remainder of this chapter is devoted to a description of methods and equipment which are employed in the analysis and in commercial oyster culture in general.

3.5 OYSTER STOCKING DENSITY

The importance of maintaining oysters at the correct stocking density has long been realised. High densities in trays and on beds have the advantage in terms of cost and ease of harvesting but invariably lead to poor growth and high mortality. The optimum stock density employed must strike a balance between losses due to overcrowding, maintenance of maximum water flow over the oysters and the cost of equipment and servicing of the oysters.

Key (1969) demonstrated that it was uneconomical to lay small oysters in trays at high densities due to their poor growth. Out of the three stock densities studied ($1.5g/cm^2$, $0.75g/cm^2$

and $0.375g/cm^2$) it was found that $0.75g/cm^2$ was the most economical to use since the differences in growth between this and the lower density were only slight.

More recent studies (Askew, ibid; Parsons, 1972; WFA, 1975; Yelf, 1978) have tended to favour lower stocking densities in the range $0.4 - 0.6g/cm^2$ for use with both trays and plastic mesh oyster bags. The current MAFF recommendation for *C. gigas* in trays is $0.5g/cm^2$. Native Flat Oysters, *O. edulis*, are usually kept at lower densities although MAFF trials have demonstrated good growth at the above density (Spencer, pers comm). This is normally applied as a target stocking density to be achieved at the end of the month's growth. Hence the thinning out of oysters should leave less than $0.5g/cm^2$ in each tray for the start of the next month.

Small oysters of less than 1.0g have been kept at densities as low as $0.1g/cm^2$ to ensure a good start to their growth. For commercial operations however, this may be unduly wasteful of tray space and a density of $0.2g/cm^2$ more acceptable. At this density 1,000 spat could be grown to 0.5g in a North West Plastic (NWP) tray.

Oysters over 10g in size are safe from crab predation and can be laid directly on to oyster beds. To facilitate harvesting it is desirable to use quite high stocking densities (there is some evidence that survival and growth of *C. angulata* is better when they are laid fairly densely (Cole, 1956)). Askew employed a stocking density of $0.6g/cm^2$ for *C. gigas* which is equivalent to 85 oysters of $70g/m^2$. Based on Cole's estimates for *C. angulata*, Parsons (1971) suggested densities of $0.4 - 0.5g/cm^2$ but this may be unduly low. Sheldon (1968) states that on commercial beds in Britain *O. edulis* may be stocked at population densities as high as $0.75g/cm^2$.

Ultimately the solution to the problem of stocking density lies in the relationship of volume of water exchanged per gramme of oyster (a mature oyster requires approximately 10 litres of water/hour). At certain sites or with particular culture techniques such as upwelling systems the suggested densities could probably be exceeded with no ill-effects. For example *C. gigas* grown to maturity in suspended lantern nets were maintained at $1.0g/cm^2$ (Briggs, 1978).

3.6 DESIGN OF ONGROWING EQUIPMENT

There are a variety of trays or growing bags currently in use in Britain. All intertidal systems require some form of trestling or frame to hold the trays off the bottom and for suspended culture techniques some form or marker and buoyancy is required. To control fouling and silting equipment needs to be air dried at approximately monthly intervals so a stock of spare trays or bags is also required. Few designs include a tray top hence in many cases an empty tray is used to avert stock loss from the uppermost tray.

3.6.1 Intertidal culture

Ongrowing units located intertidally are readily accessible for some time each day. The period of access depends on topography, location on shore and season. The position on the shore is a major determinant of growth. Exposure to air in excess of 10 - 30% of the tidal cycle will reduce growth although the exact exposure corresponding to zero growth depends on local conditions (Spencer et al, 1978). Results indicate that only a narrow band of the shore about Low Water of Spring Tide level (LWOST) is suitable for oyster culture. Better growth is achieved if the trays are supported 30 - 50 cm off the ground to avoid silting and permit maximum water flow around the oysters.

Wooden framed trays constructed of tantalised timber with an extruded plastic mesh base are used for very small spat (7 mm). The solid wooden side frame protects the spat but restricts water flow. Growth of oysters in such trays is poorer than in other designs. Parsons estimated the labour input for the construction of wooden trays as 1/6 man-hour per m^2 tray area for trays in the size range 0.5 - 1.0 m^2.

By far the most widely used tray design is that produced by North West Plastics (NWP). This tray is made of high density polythene with a growing area of 0.25 m^2 per tray. The base and sides are of 6.5 mm mesh to allow good water flow characteristics and the trays are designed to interlock closely (Plate

3.1). The trays are very durable with an expected life of five years compared to two to three years for wooden trays.

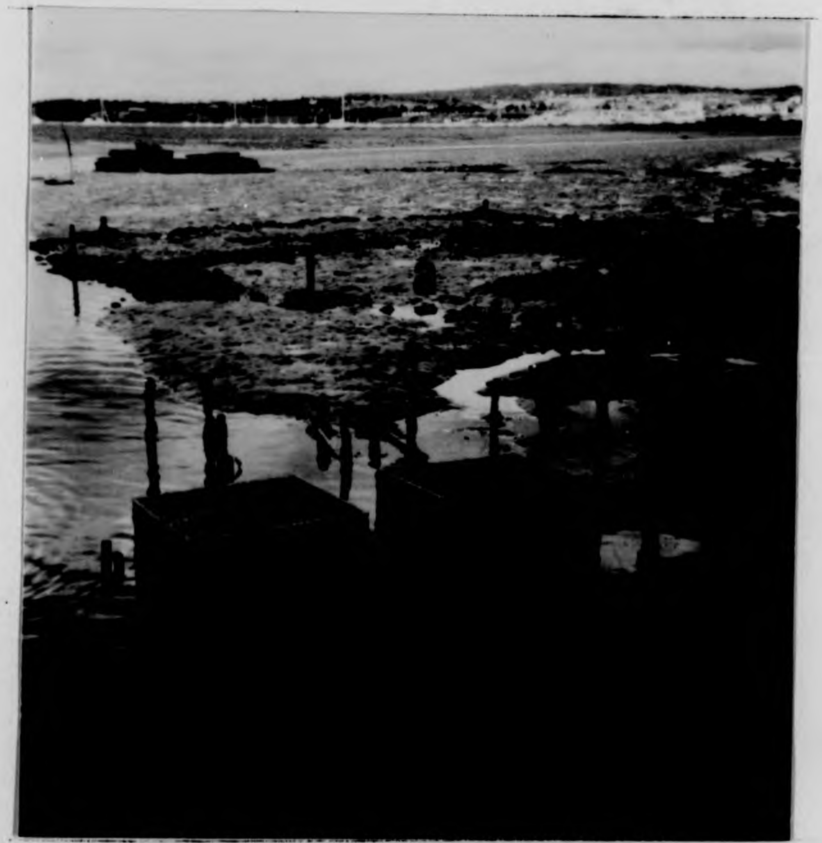
As oysters approach three grammes in weight a mesh size of 6.5 mm is unnecessary to support the oysters and hampers water circulation. At this stage oysters are normally transferred to oyster bags. Made of extruded plastic meshes either as single width or layflat tubing these bags provide an inexpensive means of ongrowing juvenile oysters (Plate 3.2). The bags are available in a range of mesh sizes and by increasing the mesh size employed densities of 200 *C. gigas*/bag have been maintained up to a market size of 70 grammes. Bags do not have a frame and have excellent water flow properties and an expected life of five years. At a size of 10 grammes oysters are safe from predation by crabs and may be laid on the bottom to ongrow to maturity thus releasing the holding units for subsequent batches.

On certain sites where the substrate is stable an alternative to intertidal tray or oyster bag cultivation is to plant out small oysters (1 - 10 grammes) within a fenced area. It is impractical to control shore crabs (*Carcinus maenas*) by trapping and so protective fencing provides an effective, inexpensive method of avoiding heavy losses through predation. The best arrangement is to construct rectangular plots parallel to the direction of the tide as this orientation minimises accumulation of seaweed and silt (Walne, 1977). The size of the plot will depend on the turnover of oysters and site conditions but the MAFF has successfully tested plots up to a size of 880 square metres. A yield of up to 100 tonnes per hectare is feasible in oyster enclosures. Fenced enclosures should have a working life of three years.

3.6.2 Suspended culture

The high survival and growth rates feasible with suspended culture must be offset against the high capital cost of equipment. Raft systems have a relatively short service life and negligible resale value (Hugeunin and Ansuini, 1978). The value of ex-hatchery oysters increases only marginally until they achieve an edible size. As oysters grow they must be

Plate 3.1



A Oysters ongrowing in an intertidal enclosure

B Ministacks of North West Plastic trays

Plate 3.1

A Oysters ongrowing in an intertidal enclosure

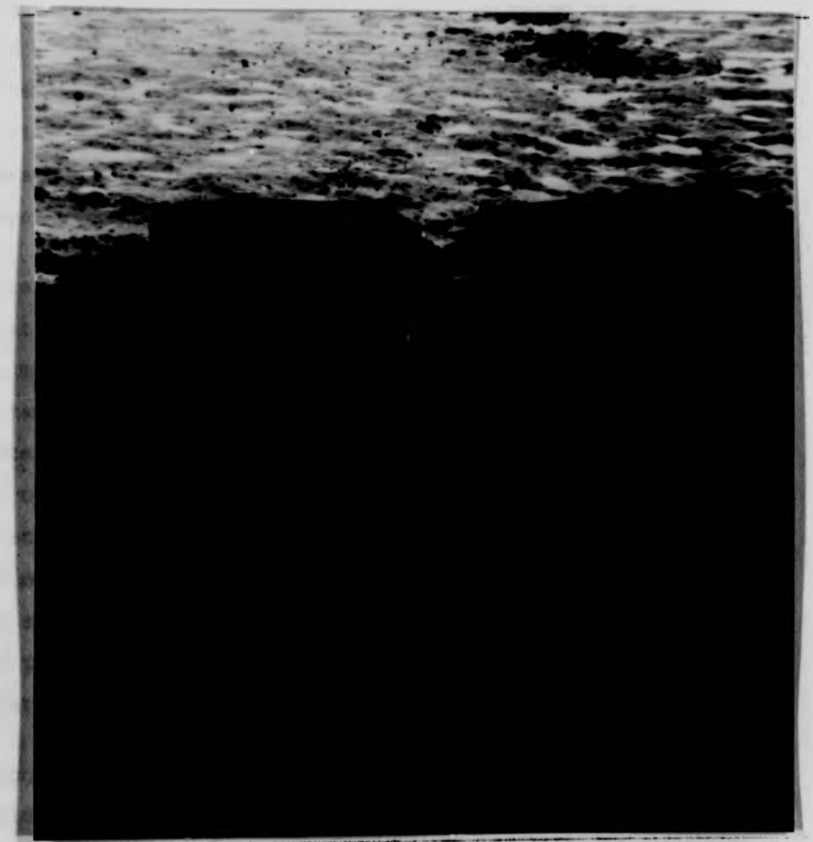
B Ministacks of North West Plastic trays

Plate 3.1

A Oysters ongrowing in an intertidal enclosure

B Ministacks of North West Plastic trays

Plate 3.2



Intertidal oyster bags of various mesh sizes

Plate 3.2

Intertidal oyster bags of various mesh sizes

Plate 3.2

Intertidal oyster bags of various mesh sizes

continually thinned out and hence the production cost per oyster increases rapidly if raft culture is employed. At present, therefore, it seems likely that the value of raft culture will be in growing small oysters up to a size suitable for relaying on the shore (Spencer and Gough, 1978).

Cuan Sea Fisheries of Northern Ireland use rafts to grow 10 mm spat in NWP trays to a size of 5 - 10 grammes. The units are wooden rafts with block polystyrene floatation measuring 12 x 6 metres. The rafts are employed over the period April - September and can hold a total of over one million 10 mm spat. Servicing is approximately 4 man days per six weeks per raft (Parsons, pers comm). The capital cost of a raft including trays and a lifting jig was estimated in 1979 as £4,000.

Lantern nets were originally developed in Japan and are a relatively inexpensive method of suspended culture. The nets are made of polyethylene mesh tubing with wire hoops providing a frame. The nets are sectioned into compartments into which oysters are inserted. They are light-weight and since they are collapsible, easy to store. Each lantern net stands 2 metres high, the support lines add another 0.5 metres to the deployed length. The nets are only suitable, therefore, for sites where there is a depth of at least three metres at low tide level. The nets may be buoyed individually from a float or suspended in a row from a common buoyed line.

Briggs (ibid) demonstrated that the condition index and meat yield of oysters grown in lantern nets was consistently better than that for oysters grown in NWP or wooden trays over the same size range and stock densities. The low level of fouling experienced contributed to the excellent flow-through characteristics of the nets. Nets currently in use have shown no sign of deterioration after two years use and a usable life of five years is assumed. In the analysis lantern nets have been employed to grow on oysters from 5 grammes to market size.

The Knapdale tray design may be used individually on intertidal frames or as a stack of four trays anchored sublittorally. The trays have a wooden frame with plastic mesh sides and base.

The growing area per tray is 0.56 m^2 and a stack of four trays may be worked from a boat if some lifting gear is used (the load bearing capacity of a stack is 60 kilogrammes). This design has been utilised in the analysis to grow oyster spat from 0.1 grammes to 5 grammes prior to transfer to lantern nets. Table 3.3 summarises the main differences between inter-tidal and suspended culture of oysters.

3.7 THE CULTURE OF OYSTERS IN HEATED SEAWATER EFFLUENT

The potential and effects of growing bivalves in the seawater effluent of power plants has been investigated by several authors (Lutz and Hess, 1979). In the United Kingdom the temperature of the effluent is usually approximately 8°C above ambient seawater temperatures and is compatible with the biological requirements for gametogenesis and increased growth of many species.

Both *O. edulis* and *C. gigas* have been successfully grown in heated seawater although results are more consistent with *C. gigas*. Survival of *O. edulis* has been found to vary between 10 - 80% for spat grown to 1 gramme and is very sensitive to the quality of the spat ex hatchery. For the slower growing *O. edulis* a size of 1 gramme (20 - 25 mm) represents approximately six months growth from spat in such systems.

The White Fish Authority growth trials at Hunterston, Ayrshire, recorded very good growth of *C. gigas* in Spring and Autumn but poor results in Winter despite relatively high seawater temperatures (Thain, pers comm). This is believed to be due to the low level of food available at this time and underlines the importance and interdependence of both factors in controlling growth.

At present oyster culture at power plant sites only appears to be commercially viable as a nursery operation in conjunction with finfish culture. Oyster spat are bought in and grown to approximately 1 gramme then sold to on-growers or returned to the hatchery. Marine Farms Ltd who operate at the Hinkley

Table 3.3 Comparison of intertidal and suspended culture of oysters

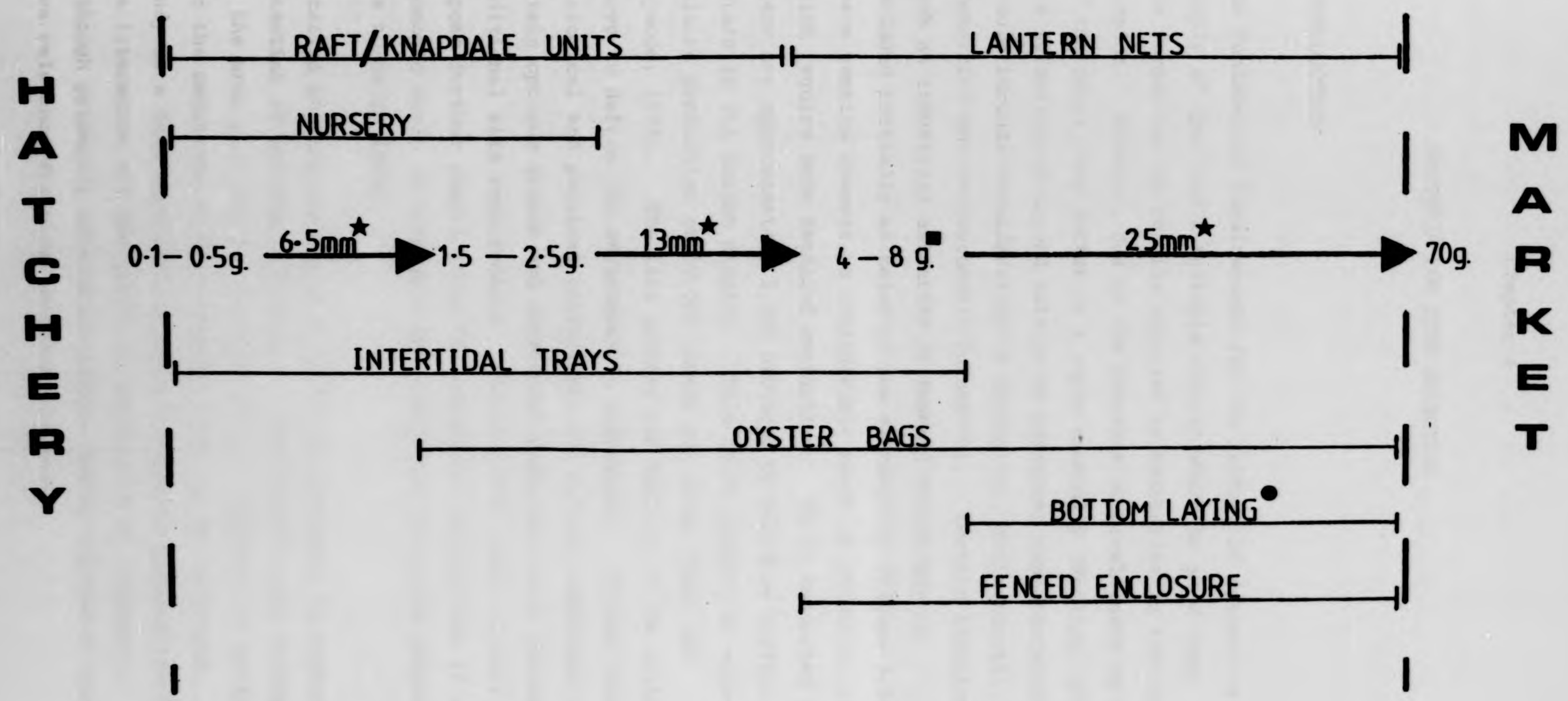
	Intertidal	Suspended
FAVOURABLE CHARACTERISTICS	1. Low Capital Cost. 2. Protection from wave action and predators. 3. Easy to maintain and service oysters. 4. Produces hardy oysters. 5. Requires no special preparation of substrate.	1. Good growth rates and high condition index of oysters. 2. Very high stocking densities feasible. 3. Access at all states of the tide. 4. Can be used where substrate unsuitable for other forms of culture. 5. Free from silting
UNFAVOURABLE CHARACTERISTICS	1. Poorer growth due to exposure to air. 2. Access only at low tide level. 3. Open to human interference. 4. Silting may be a problem.	1. High capital cost. 2. Requires shelter and slow run of the tide. 3. Requires high level of food availability. 4. May be difficult to service. 5. Subject to fouling.

Point Power Station in Somerset are already well advanced along these lines running a large oyster nursery in tandem with an eel farm. Currently they are producing over 600,000 seed oysters per annum concentrating on *O. edulis* for which there is a great demand (Ingram, pers comm).

Provided the technical problems of adequate food supply are overcome, the long term prospects for such oyster nurseries appears bright. The demand for seed and brood oysters certainly exists and at present it is uneconomic to grow spat to this size in the hatchery.

The various methods of culture which may be employed in the commercial production of oysters are summarised in Figure 3.4. The costs associated with each method of culture have been established and are given in Chapter 6. In the subsequent economic analysis the effect of using different designs on the profitability of enterprises will be investigated.

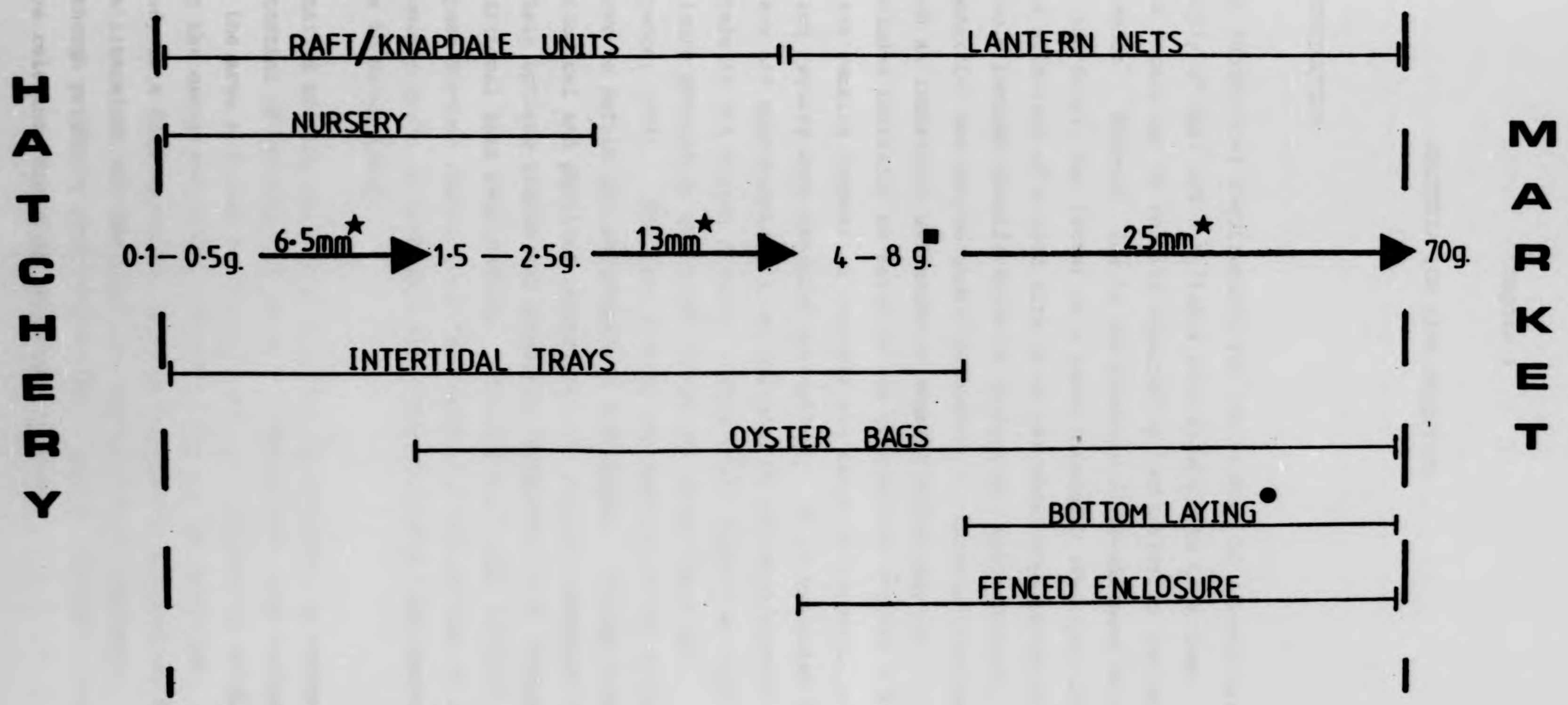
Figure 3.4 Alternative methods for the On-growing of Oysters



NOTES:

- ★ Mesh size required to hold this size range.
- ■ Maximum size for a density of 200 oysters/bag.
- ● Safe from crab predation at 10 grammes.

Figure 3.4 **Alternative methods for the On-growing of Oysters**



NOTES:

- ★ Mesh size required to hold this size range.
- ■ Maximum size for a density of 200 oysters/bag.
- ● Safe from crab predation at 10 grammes.

Chapter 4

CRITERIA FOR SITE SELECTION

4.1 INTRODUCTION

The fundamental requirements for the culture of oysters are a supply of spat and a suitable site at which to grow them. The former can be readily supplied by hatcheries in the United Kingdom. However, due to the pressure of development on much of the coast, the latter is a rarer commodity (Philips, 1973). The selection of a good site is of paramount importance and should include consideration of biological, environmental, commercial and socioeconomic parameters. Certain locations such as industrial estuaries or exposed shores may be excluded initially as being of low suitability (Figure 3.2). There remains however, a considerable range of potential sites which require more detailed evaluation. It is estimated that there are approximately 1,000 hectares of suitable coastal waters in the United Kingdom. This could support an aquaculture production of 50,000 tonnes per annum (Kerr and Haywood, 1975). The life history and habitat of the mollusc serve to define its environmental tolerances. Within these biological and physical constraints the culture technique to obtain optimum growth and commercial production will define additional site requirements. Minimum site size criteria may impose further restrictions for commercial enterprises if an economic scale of operation and acceptable return on investment are to be achieved.

Detailed on-site surveys will always be necessary to access the potential of specific locations. Nonetheless rough estimates of the area suitable for cultivation are important in establishing the magnitude of the industry which can be developed. This study is a desk appraisal of sites drawing on information from the literature and the practical experience of ongrowers. Although primarily orientated towards oyster culture it should have relevance for other molluscan species.

To date the selection of sites has been conducted on an ad hoc basis concentrating on three main factors: tidal level, bottom consistency, and protection from wave action. Little attention has been given to socioeconomic factors which although less tangible have effects which may be important (Forbes, 1969).

Recent years have seen a rapid expansion in the number of consultants prepared to carry out site surveys for a substantial fee. This represents an additional financial burden at the outset of any new enterprise. The ultimate test of any site is the performance of oysters ongrown in the sea and this may not be evident from a few days' on-site investigation. At present consultants are not bound to take the responsibility for their decisions in relation to their clients. In some cases professional surveys have proved expensive in terms of both the fee charged and the mistakes made as a consequence of poor advice (Sedgwick, 1978).

The objective of this study is to identify, where possible, the optimum ranges for the main parameters important in site selection for oyster culture. Presented with such information it will be possible for prospective ongrowers to identify quickly potential sites from maps, to access more effectively the need for the services of a consultant and if the latter are used, to satisfy himself on the accuracy and validity of the advice given. It is not intended as (and should not be construed as) a substitute for oyster growth trials at the proposed sites. Such growth trials are the only reliable way of establishing the suitability of a location for cultivation. Many traditional oyster areas on the south and south-east coast of England produce *C. gigas* with unacceptable shell:meat ratios. There is no simple explanation of this but high levels of suspended silt has been implicated as a possible cause.

4.2 ON-SITE SURVEYS

A desk survey will identify areas with the greatest potential but requires on-site investigation to establish suitability. Such appraisals need not be beyond the capabilities of the on-grower himself. A check-list of the required site information has been drawn up by the White Fish Authority (1975). A description of simple, inexpensive hydrographical equipment required and the methods of data collection is given by Landless and Edwards (1976).

Information gathered in a one or two day survey, no matter how detailed, is of limited value since it is the variability in site hydrography which offers the greatest potential benefits and risks to the culturist. The author recommends that two periods of a fortnight's duration, one during October - March and one between June - September, be spent on the survey. In this way information will be gathered during the extremes of conditions experienced at the site. More frequent recordings of water temperature, wind speed and wave action may be available from local organisations or individuals and would provide valuable additional data concerning the site.

On-site growth trials are essential. These should be conducted at the most promising site or sites for up to eighteen months. In this way seasonal changes and their effects upon oyster growth may be put into perspective. Furthermore any problems with silting or fouling will have had ample time to manifest themselves. A bonus of such trials which is often overlooked is that eighteen months is sufficient time to produce marketable *C. gigas*. Pilot scale growth trials, therefore, will provide the ongrower with oysters to conduct test marketing trials and to sound out potential buyers before he has invested the bulk of his capital. The ongrower must appreciate that oysters do not sell themselves.

The importance of pilot scale trials cannot be stressed too greatly and no amount of expert consultation can replace the information such efforts will yield. It is desirable that the initial survey be carried out at least eighteen months before the scheduled commencement of commercial operations.

4.3 HYDROGRAPHIC FACTORS CONCERNING SITE SUITABILITY

Both intertidal and suspended oyster culture are restricted to the fertile, uppermost ten metres of the water column. As a general rule it is only necessary, therefore, to consider hydrographical conditions down to this depth. The most common exception to this rule occurs where water is pumped ashore from below this depth.

Hydrographical conditions have a very wide range of effects upon the performance of oysters in the sea. Temperature directly affects their metabolic rate and hence growth. Physical parameters such as wave action may cause damage and loss to both equipment and oysters. Substrate composition will determine the types of cultivation feasible. All such factors have important, readily identifiable effects which must be considered.

4.3.1 Seawater Temperature

The warmest seawater in winter is to be found in the south-west of England where the winter minimum is 9°C. February is the month when surface seawater temperatures are at a minimum and the water column is vertically mixed. Inshore waters are normally colder than the deeper offshore water in winter, and vice-versa in summer. The entire east coast of Scotland and England during the winter lies within the boundaries of the 4 - 5°C isotherm and together with the coastline of Lancashire and Cumbria constitutes the poorest oysterage sites. Summer seawater temperatures in the British Isles seldom rise above 18 - 19°C for prolonged periods except in very shallow, sheltered estuaries. Surface temperatures may be significantly higher than the underlying water layers due to stratification of the water column and the formation of a thermocline. Seawater temperatures begin to decline in late August or September when the removal of heat by vertical mixing begins to exceed solar radiation. On the west coast of Scotland the average seasonal seawater temperature range is only 7.5°C reflecting the presence of the deep water found in this region (Gage, 1974).

The temperature of the sea affects both the growth of the oyster and the condition of the oyster meat. For *O. edulis* temperature controls both the beginning and end of the growing season but the rate of growth between these limits also depends upon other factors (Walne, 1958). Native Flat Oysters are best suited to a slightly lower temperature range than *C. gigas* (Table 4.1). Both species have a relatively wide temperature tolerance and can survive mild frost for up to several days. In areas where severe frosts occur the oysters must be kept submerged by the tide at all times in winter. *O. edulis* is more tolerant of frost than *C. gigas* and consequently if Low Water Spring Tides (LWST) occur in winter between midnight and 0300 am it is safer to grow *O. edulis* rather than *C. gigas* intertidally.

High water temperatures (>20°C) in shallow waters during the summer should be avoided as the oysters are likely to be of poor quality due to stress and limited food. Similarly high winter temperatures when food availability is limiting will yield poor quality oysters.

4.3.2 Salinity

With the exception of estuaries, salinity is not as important for oyster culture as it is for scallop culture. If oysters are ongrown on the sea bed then surface runoff may be important even if there is no obvious source. In the sea, if layering occurs, the halocline forms at the surface (0 - 5 metres), but is only substantial around LWST when the lowest salinities occur. The problem of freshwater inundation may be avoided altogether if oysters are maintained below low water level. Native Flat Oysters grow best in a narrow band of salinities just below that of normal seawater. The Pacific Cupped Oyster is somewhat more tolerant of lower salinity levels. The best areas for fattening oysters are usually those where some fresh-water drainage from the land occurs.

4.3.3 Degree of site exposure

The extent to which a location is exposed to the action of storms and bad weather in general is one of the most important factors determining site suitability. As few as one storm

Table 4.1 Temperature (^{o}C) and Salinity (S^{o}/oo) ranges suitable for the marine cultivation of bivalve molluscs

PARAMETER	SPECIES			
	Ostrea edulis	*Crassostrea gigas*	*Pecten maximus* (Scallop)	*Mytilus edulis* (Mussel)
Preferred salinity range	28 - $32^{o}/oo$	24 - $30^{o}/oo$	30 - $34^{o}/oo$	30 - $44^{o}/oo$
Minimum salinity for cultivation	$25^{o}/oo$ [b]	$18^{o}/oo$ [b]	$28^{o}/oo$ [c]	4 - $5^{o}/oo$ [d]
Annual temperature range for required growth	5 - $18^{o}C$ [e]	10 - $20^{o}C$ [e]	12 - $18^{o}C$	10 - $20^{o}C$ [f]
Time to reach market size under preferred conditions	4 - 5 years (80 - 130 mm)	2 years (100 - 110 mm)	3 - 4 years (95 - 100 mm)	2.5 - 3 years (65 mm and over)

Notes

a. *P. maximus* is only cultured sublittorally (15 - 25 m).
b. Tolerant of lower levels for short periods.
c. Scallops are very sensitive to salinities below $28^{o}/oo$.
d. Mussels are euryhaline.
e. Both species can survive at lower temperatures and even mild frosts for periods.
f. Temperature tolerance is 0 - 26°C lower temperatures being tolerated better than higher temperatures.

every two years may cause sufficient damage to oyster grounds as to render an operation unprofitable. It is important that any site chosen is sheltered. This is very difficult to access accurately from maps and charts and for waters of less than 15 metres depth can only be reliably measured with wave meters (Darbyshire and Draper, 1963). The two principle forces involved are wind action acting on structures above the water level and wave action. The latter is potentially the most damaging, wave lengths comparable to the length of the oyster raft causing the most damage. The degree of exposure depends on several factors:

(i) Characteristics of the wind field
(ii) Direction and speed of the wind field
(iii) Extent of open water across which the wind is blowing (the fetch)
(iv) Water depth variation along the fetch.

It is not the 'typical' wave size which is important but rather the size of waves likely to be generated during a storm at the site. It is possible to predict the height of these 'significant' waves and hence the degree of site exposure if the fetch and the mean wind speed and direction are known (King, 1972; Landless and Edwards, ibid). Both parameters may be readily obtained from navigational charts and meteorological data. For example a fetch of 3 km and a mean wind speed of 20 m/sec (Beaufort scale 8) would raise waves of 0.75 - 1.0 metres in height.

By employing such information it is possible to establish the feasibility of certain types of culture at a proposed site. Locations where waves greater than 0.3 - 0.5 metres in height may be generated are generally considered unsuitable for raft culture (Quayle, 1971). Buoyed subsurface techniques should be able to withstand waves of up to 1.5 metres in height. As a general rule for suspended culture, the effects of the wave force penetrate to a depth equivalent to half the wave length. Therefore, oyster trays and lantern nets should not actually be supported at the sea surface but 0.5 - 1.0 metres below it where the effects of wave action are reduced. The dredging of oysters is restricted by access to oyster grounds rather than by the degree of exposure acting directly upon the beds. Intertidally, sites where breaking waves are common are likely to be rejected on the basis of several criteria including unstable substrate or excessive periods of aerial exposure.

4.3.4 Tidal movements and currents

The Admiralty atlas of tidal currents, tide tables or local knowledge are all valuable sources of information concerning the direction of tidal streams and duration of slack water. The speed and direction of tidal currents is important primarily for anchored structures. A maximum current speed of 65 cm/second is recommended by the WFA for aquaculture in general. Areas of high water exchange may permit the use of higher stocking [illegible] sublittoral culture are best suited to low tidal ranges. Exposure to air for less than 10% of the tidal cycle yields the best results with intertidal culture. The best intertidal growth results have been recorded about zero tidal level (chart datum) although in Britain most cultured oysters are grown in the 1.0 - 1.5 metre zone where the tidal range is approximately 4.5 - 5.0 metres. To achieve the best compromise between growth and access intertidal sites should be about 0.2 metres above chart datum. Where suspended culture is employed to avoid contact with the substrate a minimum depth of 4.5 - 6.0 metres at low tide is advisable.

4.3.5 Bottom topography

The most important aspect of the bottom topography is its stability since an unstable deposit may lead to the oysters becoming smothered. The best substrates are a mixture of sand, mud and/or gravel. Soft muds indicate a depositing shore where silting will occur. High levels of fine suspended particles have been shown to cause poor growth of *C. gigas* but the relationship is less clear for *O. edulis* (Key and Nunny, 1976). Soft clean and rippled sands are also unstable and rock bottoms create anchorage problems. Ongrowers have suggested that a sand and mud deposit on which a person does not sink more than 2 - 5 cm is the desirable substrate consistency. Softer deposits are tolerated more readily by *C. gigas* than by *O. edulis*.

The ideal intertidal conditions are a large area between Extreme Low Water of Spring Tide Level (ELWST) and Mean Low Water of Neap Tide Level (MLWNT) associated with a water depth of approximately 2 metres at ELWST for most of the lunar cycle. A steep shore favours suspended or sublittoral culture. Where scallop culture is considered easy access to a depth in excess of 20 metres adjacent to the shore is desirable.

4.4 BIOLOGICAL CRITERIA FOR SITE SELECTION

The distribution of oyster populations past or present does not necessarily indicate that a site is one which promotes good oyster growth. The determining factor governing the distribution of most natural populations is the availability of a suitable settlement surface for spat. Many natural populations contain a high proportion of thin, stunted individuals. This has long been realised by oyster fishermen who may transfer juvenile oysters from natural beds to fertile fattening grounds.

It has been stated earlier that the ultimate test of the suitability of a site is the growth performance of oysters in situ. Determination of an average annual growth rate of oysters in British waters provides a standard against which the local growth rate may be gauged. The suitability of the site may then be judged in terms of whether growth is greater or less than the average rate. Sufficient information to make such a comparison will be provided by the pilot growth trials.

Walne and Spencer (1971) have established the relationship between initial weight of *C. gigas* and weight attained after one year at a number of sites. A similar relationship for *O. edulis* has been derived by Walne and Mann (1975). The author has used this and similar data to derive growth curves for oysters based on von Bertalannfy growth equations (Gullard, 1969). These curves (Figure 5.2) together with a survey of recorded oyster growth rates (Table 5.1) are presented in Chapter Five. Together they provide the ongrower with a 'yardstick' against which he may measure the performance of oysters at his own site.

The distribution of other species of marine organisms has been suggested as possible biological indicators of site suitability. For example large mussel banks accumulate silt which would quickly smother oysters. They should, therefore, be avoided. Starfish and slipper limpets indicate general suitability but are oyster predators and competitors.respectively. In general sessile marine organisms have different environmental tolerances to oysters and are not accurate indicators of site suitability.

The quantity and quality of phytoplankton food is an important determinant of oyster growth. It has been demonstrated experimentally that changes in the growth of both *O. edulis* and *C. gigas* correlate to variation in the phytoplankton (Walne and Mann, ibid). At present, however, little is certain regarding the nutrition of oysters in the sea. The subject of food availability is discussed more fully in Chapter Five. It is sufficient to state here that it is not practical to use microscopic examination of the phytoplankton in the process of site selection.

4.4.1 The distribution of disease and pests

The Ministry of Agriculture, Fisheries and Food has powers under the Sea Fisheries (Shellfish) Act 1967 to control the laying of shellfish in (inter alia) tidal waters in England and Wales. In an attempt to prevent the spread of known pests such as the American Slipper Limpet (*Crepidula fornicata*) and to avoid the introduction of new diseases such as "Aber Disease" from France, the Molluscan Shellfish (Control of Deposit) Order 1974 was introduced (see Key, 1977b). Similar legislation has been passed for Scotland and Northern Ireland.

Under these Orders it is an offence to move live oysters and mussels and in some instances also the shells of any other type of molluscan shellfish from an infested area to one designated as pest-free or of a lower instance of infestation. To date this has succeeded in restricting the distribution of pests and instances of disease to the south and south east coasts of England.

To facilitate the operation of existing ongrowers and hatcheries the MAFF issued a number of general licences to cover shellfish movements. However, if the distribution of pests changes or an ongrower wishes to relay oysters from an area not covered by a general licence an individual licence for the deposit approved by the local District Inspector of Fisheries is required.

Ongrowers should be aware of the restrictions imposed by this Order when considering the movement of clutch, spat or brood oysters between designated areas. Where possible the investor should favour sites which are known to be free of pests, disease or other contaminants.

4.5 RIGHTS AND OWNERSHIP OF THE FORESHORE

In the United Kingdom, with the exception of areas previously sold or granted to private or corporate interests, the foreshore (Mean Low Water Spring Tide Level up to Mean High Tide Level), the seabed as far as the national territorial limits and the beds of tidal rivers and creeks belongs to the Crown. In Scotland the Crown Estate Commissioners administer approximately 40% of the foreshore and the percentage in England and Wales is of a similar level.

Sole rights to the use of the foreshore are essential if an oyster grower is to adequately protect his investment in stock. To secure these rights whether it is to lay shellfish, erect installations or moor rafts to the seabed requires a lease from the Crown Commissioners (private owners usually follow the Crown's valuation of the foreshore). Leases are granted for a period not exceeding one hundred years, subject to the conditions that the proposed activity does not:

(i) Materially obstruct or endanger navigation (Coastal Protection Act, 1948)

(ii) Interfere with fishing

(iii) Contravene the Dumping at Sea Act, 1974

(iv) Gains approval from the relevant Local Authority under Town and Country Planning Legislation.

In Scotland some forty to fifty operators hold rights to the sea-bed principally on the west coast (Mason, 1980). To date only a handful have attained commercial production.

The prospective ongrower is recommended to contact the Crown Commissioners to ascertain ownership and present status of potential sites as soon as they are identified by the desk survey.

A land base of some form will be required for all but the smallest enterprises. If water is to be pumped ashore the land base should not be more than ten metres above the submerged inflow. It is not essential that the land base be adjacent to the ongrowing site although the White Fish Authority recommend that it be no more than five miles from the location. A short distance between the two areas is clearly advantageous in terms of both stock management and security. The presence of existing facilities such as access roads, jetties or slipways in the proximity of the ongrowing site should also be sought. The size of the site required depends on the proposed scale of operation but an average figure would be sufficient for present usage plus 50% for future expansion. A five hectare site would be adequate for intertidal oyster culture.

4.6 PROXIMITY TO HATCHERIES AND MARKETS

Commercial shellfish hatcheries are well distributed throughout the United Kingdom (Figure 3.2) and no site is likely to be more than one day's travelling distance from a source of oyster spat.

If correctly packed spat will survive out of water and their supply should not constitute a constraint on site selection.

Location in relation to markets and access to transportation facilities are important considerations. It may be possible to market oysters locally. The main outlets for oysters are to hotels and restaurants but the winter harvesting of oysters coincides with the slack season for coastal resorts. Local markets alone may be insufficient to support the proposed level of production. This is particularly true of Scotland where production is centred on the sparsely populated west coast. Oysters are a valuable crop and can bear quite high transportation costs but proximity to large population centres, processors or co-operative marketing organisations are to be rated highly.

4.7 SOCIOECONOMIC CRITERIA

The site evaluation process must take account of how the venture will affect the community in which it is to be located. A fishing community may far more readily accept aquaculture than one which is dependant on recreational activities. Most research on socioeconomic parameters has been conducted in urban areas (Lawton, 1968; O'Farrell and Markham, 1975). The general depopulation of rural areas particularly in Scotland has given support to the view that similar studies would not be necessary in sparsely populated areas. Little quantitative information on socioeconomic factors in rural areas is available. Since most oyster culture sites are in isolated areas an attempt is made to quantify certain factors in order that they may be included in the sieving out of suitable sites.

The measurement of labour availability in rural areas is fraught with difficulties. The size of the desired labour force depends on the scale of investment and the efficiency of operation. Fishing communities are the most likely source of suitable labour although supervisory and managerial roles are likely to be filled by the investor or a manager brought in from outside the community.

The journey to work is an important consideration. Workers in rural areas are normally prepared to travel further than their urban counterparts. Apart from the physical distance, important considerations are the level of earnings, other job opportunities and the availability of transportation. In a study of farm agricultural workers it was established that 50% of the subjects were not prepared to travel more than three miles to work (Newby, 1977). However, the more highly qualified stockmen and foremen were prepared to travel further than farm labourers. In an earlier study a distance of seven miles is quoted as being acceptable (Drudy and Wallace, 1971). The Highlands and Islands Development Board which operates in the region with the greatest potential for aquaculture has no guidelines on this subject but suggests a travelling time of up to 0.5 - 1.0 hours as acceptable for the journey to work.

In rural areas transportation costs are likely to be high and may be a constraint on site selection. However, co-operative marketing may reduce these costs. Some individuals may express a desire to establish ventures in particularly remote areas and select sites accordingly. The author believes that the investor should aim to have a suitable pool of labour within a five mile radius of any proposed site.

4.8 SUMMARY

Scotland has by far the greatest potential for the development of finfish and shellfish culture. Over 80% of the sites identified by the WFA were on the west coast of Scotland. Assessments of the total area which could be exploited for oyster culture are difficult to make. In view of the variety of cultivation methods available it is concluded that the availability of sites is unlikely to prove the factor which will limit the development of the oyster farming industry.

The author has sought to emphasise and where possible quantify the diverse range of parameters which the investor must evaluate when appraising potential sites. Not all of the constraints involved in this sieving process are of the same level of importance but the allocation of specific weighting factors based on relative importance is not easy. The assumptions necessary to construct a rigourous site evaluation scheme would render it cumbersome to use and negate the advantages of such a survey. Each site must be independently appraised.

It is hoped that the information presented in this chapter will go some way towards giving the investor a broader perspective of what constitutes a good site and aid him in reaching an objective assessment of potential sites. It cannot be stressed too strongly that such information constitutes only the initial phase of site evaluation. Pilot scale oyster growth trials as described earlier are the only accurate test of a site's suitability.

Chapter 5

MODELS OF OYSTER GROWTH AND MORTALITY IN THE SEA

5.1 GROWTH IN THE SEA

Growth may be considered as the quantitative aspect of development, the rate of which is unique to each species and each stage of development. Rapid growth and a large size provide protection against predation and makes exploitation of larger food items possible. Cushing (1975) postulated that animals grow to avoid death hence for the individual growth can be regarded as a competitive process by which death is avoided for as long as possible. This inverse relationship between size and mortality is one of the basic principles upon which oyster populations have been modelled and will be returned to later.

There is a general tendency for the growth rate of oysters to decrease with increasing size (Askew, 1976; King, 1977; Spencer and Gough, ibid). It appears that together with size, season is the main determinant of growth although stocking density and method of culture may also be important. Seasonal effects on growth, mortality and condition index[1] influence the productivity of a brood or cohort and may cause substantial variations in yield. The temperature of the sea and the availability of phytoplankton food have been identified as the principle agents controlling oyster productivity.

The growing season of oysters normally begins in April and lasts until October; most of the growth is completed in the first few months of the season. Up until June - July the rate of growth of *C. gigas* is greater than that of *O. edulis* thereafter the rates for both species are similar (Walne and Mann, ibid). It is during the first few months that most of the meat

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1. Condition Index is a measure of the condition or quality of the oyster (Walne, 1970b).

growth occurs, the amount being predominantly determined by food supply (Quayle, ibid; Walne, 1971). Shell growth occurs later and is more dependent on temperature. Winter growth may occur with *C. gigas* and this may be economically important in reducing the time to reach market size.

Walne (1975) states that the average annual growth increment of a twenty gramme or over *O. edulis* is eighteen grammes (range 10 - 30 grammes). The actual amount depends on the food supply but for most individuals the increments tend to be fairly regular. The growth rate of *C. gigas*, by comparison, is much faster; a 5 gramme oyster growing at 3 grammes/month, a 25 gramme at 7 grammes/month, and a 50 gramme oyster at 10 grammes/month (Walne and Spencer, ibid). Only for *C. gigas* over 50 grammes are the growth increments regular. A summary of recorded oyster growth rates at locations spread throughout the United Kingdom is given in Table 5.1.

5.2 MORTALITY IN THE SEA

At any point in time a certain proportion of a population of animals are lost through death. This loss may result from a specific factor or a combination of factors which may or may not be identifiable. In this study mortality is classified into two categories: natural background mortality, the level of loss due to which is variable but generally low; and mass mortalities which are sudden, widespread and usually attributable to a specific change in the physical or biological environment.

5.2.1 Background mortality

In this study it is assumed that the background mortality rate declines with increasing size over the size range considered. This assumption that the number surviving follows a logarithmic decline is taken to imply that natural death is due to a large number of causes acting randomly and that the probability of an individual dying between time t and t + Δt is constant (Beverton

Table 5.1 Recorded growth rates for intertidal and bottom laid oysters at selected sites in the United Kingdom

Species	Time to market size	Location	Author(s)
C. gigas	2 years	Emsworth Harbour	Askew (1972)
O. edulis	4-5 years	Essex	Cole (1956)
C. gigas	18 months (60g)	Essex	Davidson (1974)
C. gigas *O. edulis*	18 months 3-4 years	West Scotland	Ley (1979)
C. gigas *O. edulis*	18-24 months 4-6 years	Scotland	Mason (1972)
C. gigas *O. edulis*	18 months (min) 3-4 years	Northern Ireland	Parsons (1971)
O. edulis	4-6 years	Anglesey	Walne (1958)
C. gigas	2-3 years	Various sites	Walne & Spencer (1971)
C. gigas	15-18 months	Devon	Yelf (1978)
C. gigas *O. edulis*	18-24 months 4-5 years	Anglesey	Anon. (1974)
C. gigas	2 years	Dorset	Anon. (1979a)

and Holt, 1957). Observations of oyster mortalities in culture systems show good agreement with this hypothesis.

The level of background mortality is very variable. Parsons (1974) recorded it as less than 5% per annum for *C. gigas* of over 0.5 grammes held in trays. Annual mortalities of adult *O. edulis* on the Stanswood oyster grounds over the period 1971 - 1972 were estimated at 1% (Key, 1972). Higher annual mortalities in the region of 20% were recorded in Emsworth Harbour by Askew. In general annual mortalities between 10 - 15% can be expected for juvenile and adult oysters held in the sea (Walne, 1961; Key, 1970; Walne and Spencer, ibid; Parsons, 1972). Mortalities amongst oyster spat can be expected to be much higher. Irrespective of the size of oyster considered frequent cleaning, regrading and general good management will keep background mortality to a minimum.

Seasonal mortality patterns have been recorded by several authors but the mechanisms by which they are determined appear complex. Spencer and Gough recorded a direct relationship between temperature and instantaneous mortality rate (Z30) for *O. edulis* up to 5 grammes but the relationship did not hold for *C. gigas*. Summer mortality peaks frequently occur and may be the result of the combined effect of high temperature and low food supply inducing physiological stress.

5.2.2 Mass mortality

Mass mortalities have been studied in some depth because of the scale of their effect on a fishery. In the early 1970s an outbreak of an epizootic disease generally referred to as 'Aber Disease' was reported from Brittany, France. Within two years over 60% of this profitable fishery had been destroyed. This outbreak closely resembled an earlier epidemic which decimated the British oyster industry in the 1920s and from which it has never fully recovered (Alderman, 1974).

During the severe winter of 1939 - 1940 the stock of British oysters was reduced by 50 - 60% (Cole, 1940). In the winter of 1963 an estimated 95% of the oysters in the River Crouch, Essex, were lost as a result of freezing conditions (Davidson, pers comm). It is often difficult to distinguish the effects of low temperature and low salinity in such circumstances since many deaths occur when the temperature starts to rise. Oysters in poor condition are often unable to survive inundation with silt or low salinity water when thawing commences. At high temperatures when food availability is low mass mortality may occur. Growth trials with *O. edulis* in Malta recorded catastrophic mortalities (100%) when seawater temperatures reached 25^{o}C (Agius et al, 1978).

Clearly such incidences have an immediate impact from which the fishery may never recover fully. Their occurrence whether it be due to a climatic extreme or disease outbreak is unpredictable and would necessitate the introduction of random elements and stochastic rather than deterministic modelling. At present there is insufficient data upon which to base an accurate estimate of the probability of occurrence of a mass mortality. In view of this problem its consideration in the generalised mortality model was not considered justified. However, rather than simply ignore such a potentially important factor an allowance for the uncertainty associated with such an event may be included in the economic appraisal of a project. The subject will be returned to later but techniques including sensitivity analysis, truncation of the economic life of the project and employment of a higher than normal discount rate are all commonly employed to cope with uncertainty.

No clear distinction exists between the two categories of mortality but some guidelines may be sketched in. Mass mortalities in the literature usually describe losses in excess of 50%. Several authors appear to regard losses of up to 25% p.a. in growth trials as not excessive. An independent assessment is that used by aquaculture insurance underwriters who attempt to exclude low level 'run of the mill' losses by the inclusion of a franchise clause in policies (see Chapter six). For oyster production this franchise is set at 35% stock loss excluding disease and for all losses including disease at 50 - 70%

stock loss at any time. On the basis of these figures and mortality rates published in the literature the author proposes the following classification of oyster mortalities:

% mortality per annum	Category of mortality
<5%	Low
5 - 25%	Acceptable
25 - 40%	High
>40%	Mass

All mortality rates predicted by the model used by the author fall below the 35% franchise level and may be considered as background mortality.

The cost of oyster production depends largely on the length of the growing period. Given information on growth and mortality it is possible to estimate the production cycle, yield and to select appropriate starting size and date to optimise the effects of seasonal growth. The author has derived a generalised, deterministic model of oyster growth and mortality which is sensitive to environmental change and can be employed to evaluate the economics of different growing systems and to optimise production scheduling.

5.3 FOOD AVAILABILITY

Together with temperature the abundance and nature of the food supply may be expected to be the major factor determining oyster growth rate in the sea. Early research recorded observations on the nature of particles ingested but this has been shown to be an unreliable guide to food value. Studies of phytoplankton abundance are generally qualitative rather than quantitative and rarely correlated the distribution of algal food to oyster growth rate. Many species of phytoplankton may be ingested by oysters but all will not be digested and those that are vary markedly in their food value (Walne, 1970a). The food requirements of the larvae of some species of marine bivalve have received considerable attention because of the species' commercial value. The nutritive needs of oysters in the sea, however, are poorly understood (Wilbur and Owen, 1964; Walne, 1975; Askew, 1976). The value of a particular algae as food varies through the oysters' life possibly reflecting a changing ability to digest the plant cell wall protein. Attempts to correlate the chemical composition of phytoplankton species to their dietary value have met with little success (Epifanio, 1979). Evidence of synergetic effects in the relative food value of mixed diets has been found and supports the hypothesis that the quality of a species as oyster food depends more on the presence of some growth promoting micronutrients rather than the gross chemical composition. It is widely acknowledged that certain species such as *Isochrysis* and *Tetraselmis* are good oyster food and other species including *Chlorella* poor food. Walne was able to arrange algal species into a hierarchy based on their suitability as food for juvenile oysters but these laboratory experiments employed only pure algae cultures. Algae which give good growth rates with oyster larvae have also been shown to give good results with juvenile oysters and suggests that they may be a good food for larger oysters also.

Both *O. edulis* and *C. gigas* are discontinuous feeders feeding only during the day (Morton, 1971, 1977; Langton and Gabbot, 1974). Superimposed upon this cycle is a tidal rhythm which synchronises the oyster to its environment. Work with the American Oyster (*C. virginica*) suggests that oysters are able to adapt their feeding level to fluctuating levels of food presented to them; the optimum food level being 300 - 350 microgrammes/litre (Tenare and Dunston, 1973). Walne recorded the optimum food concentration for *O. edulis* growth as $5{,}000\mu^3$ of algal matter per litre and in a later paper showed that oysters need to ingest more than 3×10^5 particles of 5 - 10μ per minute per gramme of dry flesh to obtain sufficient food for growth (Walne, 1972).

A detailed study of the food value of the unicellular algae *Tetraselmis suecica* for oyster spat recorded the optimum algae density as 10^7 per spat (Walne and Spencer, 1974). This is one of the few species for which estimates of the conversion efficiency of food are available. The authors estimated that 63% of the added food was assimilated by the spat and the conversion efficiency to dry meat was 16 - 31%. In an earlier study the assimilation efficiency of small mussels, *Mytilus edulis* fed *Tetraselmis* was recorded as 86% when fed 1.5 cells per μl (Widdows and Bayne, 1971). Bivalve molluscs appear able to regulate the rate at which they take up food in accordance with the level of food available. Such studies give some indication of the feeding capabilities of spat but are invariably conducted in the laboratory under ideal conditions. There is still a great deal to learn regarding the food value of mixed phyto-plankton in the sea.

Most of the water pumped by an oyster is used for feeding and the rate of pumping depends on temperature. Askew concluded that the seasonal growth pattern of *O. edulis* could be adequately explained by a combination of food availability and temperature. However, the earlier Spring and Summer growth of *C. gigas* cannot be governed in the same way. Food supply, which peaks before temperature, was believed to be the dominant factor determining the seasonal growth of *C. gigas*. Observed variability in the annual growth increment of oysters may be explained in part by changes in feeding activity and subsequently growth resulting from fluctuations in temperature, phytoplankton density and composition.

Both the concentration of food and the rate at which it is brought to the shellfish are important independent factors. In estuarine situations food concentration tends to be the more constant of the two, seldom varying by more than a factor of ten. Water flow rate which depends on a host of factors can vary from static to several knots. It is primarily the variability in water movement rather than food concentration that is responsible for the wide range of shellfish productivity which occurs in different estuaries or area of the same estuary (Ryther, 1969).

Theoretical curves relating oyster growth, temperature and food supply have been presented by Malouf and Breese (1977). These propose an inverse relationship between temperature and growth rate at very low levels of food availability and a direct relationship when food is abundant. The mechanisms controlling these relationships are complex. It is postulated that oysters have increased metabolic costs at high temperature and that these costs are reflected in weight loss when food is scarce. Alternatively assimilation efficiency may be inversely related to temperature such that less energy is available for growth at high temperatures than at low temperatures.

The subject is one which requires further investigation but the general picture which emerges is that the quantity, quality and rate at which food is supplied are important. Quantitative and qualitative differences in the food contained in the water, along with temperature, determine growth. Askew has gone some way towards quantifying these relationships for oysters in the sea but the resultant models appear to be far from simple. In view of the incomplete understanding of the role of food and the lack of other supportive studies the author does not consider it feasible to include food availability in the models developed in this thesis. The use of temperature alone as the environmental determinant of growth is an oversimplification but one which appears unavoidable at present. Pilot growth trials at the selected site will establish whether food supply is adequate and will validate the growth rates derived from the models. The omission of food availability from the model is justifiable provided pilot growth trials to establish oyster performance are included as part of the total project appraisal. Food levels in coastal areas dominated by oceanic currents eg Western Ireland are oligotrophic and the model developed in this thesis is not applicable to such sites.

5.4 THE DERIVATION OF MODELS OF OYSTER GROWTH AND MORTALITY

Descriptive models should contain as few parameters and initial conditions as is consistent with accuracy. Each factor included in the model should have some biological meaning. Even if the proposed model gives a good fit to field observations this in itself does not provide a critical test of the hypothesis underlying the model. This requires experimental and field studies of the mechanisms postulated.

Oyster culture lends itself particularly well to modelling since several factors important in the simulation of finfish populations can be disregarded, eg natural recruitment, immigration and emigration or fishing effort. To produce a general model to predict oyster yield requires long term recordings of growth and mortality at different sites. The MAFF have published several papers describing growth curves for both species of oyster. However, the major contribution to this field has come from Askew (1976, 1978). From growth and survival data collected at two sites on the south coast of England over a number of years he was able to derive a general model based on instantaneous growth and mortality rates in relation to oyster size.

In this study two different models are proposed to account for oyster growth. The first employs standard von Bertalannfy growth equations using size expressed as weight. The second is a multiple regression model based largely on field growth data presented by Askew. The principle innovation of this latter model is the inclusion of seawater temperature as a factor determining the growth rate.

5.4.1 Askew's model

The model is based on generalised observed trends in growth and mortality in relation to size (Askew, 1976, 1978). It differs from many other earlier studies in using monthly time intervals rather than annual or seasonal growth periods. This was made possible by the extensive growth studies carried out in Langstone and Emsworth harbours over several years. Where data was missing published information from other studies was included in the model. The employment of monthly time intervals facilitates consideration of seasonal patterns and makes the model sufficiently flexible to investigate the effects of varying initial size and month of laying on the ongrowing operation.

The model attempts to quantify the observation that the rates of relative growth and mortality decrease as size increases. These relationships are expressed as annual instantaneous growth rate (G) against weight and 30 day instantaneous mortality rate (Z_{30}) against initial weight.

where $G = \log_e \frac{W_t}{W_o}$ W_t and W_o are the mean weights at the beginning and end of time t

and $Z_{30} = \log_e \frac{N_o}{N_t}$ N_o and N_t are the number surviving at the start and end of time t, in this case 30 days.

The central assumption of the model is that short term instantaneous growth rates (G_{30}) concur with the trend for annual instantaneous growth rates. It is assumed that these curves can be used to scale observed monthly growth rates to any standard weight or to any other specified weight to derive the likely growth of different sizes grown under the same conditions.

The first step in using the model is to scale the observed oyster size to a standard size by using the ratio of annual values for the instantaneous growth rate (G). The appropriate monthly instantaneous growth rate is extracted from a smoothed seasonal growth curve based on the Emsworth harbour site (G_{30}*). The ratio of the annual values of G is multiplied by the extracted G_{30}* value to derive the G_{30} value for the first time period (G_{30}**).

$$G_{30}^{**} = \frac{G(\text{Observed})}{G(\text{Standard})} \times G_{30}^{*}$$

The weight the oysters have attained at the end of this time period (W_t) is calculated by adding the derived G_{30}** value to the natural logarithm of the initial weight (W_o) and taking the antilogarithm of the sum.

$$\log_e W_t = \log_e W_o + G_{30}^{**} \quad .... \quad \text{Eq 5.1}$$

The derived final weight for the time period becomes the initial weight for the following month. The procedure is repeated until a predetermined size is reached.

The initial weights for each month are used to establish corresponding mortality coefficients (Z_{30}) from generalised mortality curves. In view of the scarcity of suitable data the general mortality function is an aggregate plot combining observations for both species and at several sites. Different rates of mortality are achieved by including the 50% confidence limits about the regression curve to yield low, medium and high rates of mortality. The number of oysters surviving at the end of each month (N_t) is obtained by subtracting the mortality coefficient from the natural logarithm of the initial number (N_o) and taking the antilogarithm of the result.

$$\text{Log}_e N_t = \text{Log}_e N_o - Z_{30} \quad .... \quad \text{Eq 5.2}$$

The number surviving at the end of each time period is used as the initial number for the following period.

The reiterations required to construct a growth curve in this manner are both laborious and time consuming and lend themselves to the use of a computer.

The author originally intended to use this model to investigate the economics of oyster culture. A computer programme was written to generate growth and mortality data. However, it was discovered that although the predicted growth rates for *C. gigas* were acceptable those generated for *O. edulis* were in excess of any reported for field growth trials in the United Kingdom. A more rigorous appraisal of the original data used to formulate the relationships between instantaneous growth rate and oyster size brought to light certain factors which explain this result. Two factors are significant. Firstly, as a result of the scarcity of data regarding the growth rate of small oysters the annual instantaneous growth curve presented is not as accurate as would be desired. Attempts by the author to update this curve by the inclusion of data from other sources did not significantly improve the relationship.

Secondly it would appear that the proposed seasonal growth pattern for *O. edulis* based on Emsworth harbour is atypical. The growth curves generated by its use are overoptimistic. The repeated use of the same seasonal growth curve over successive years tends to amplify the difference between predicted and observable growth rates. This is accentuated by the employment of a simple ratio of annual growth rates in the model.

Variation in growth rate in this model is achieved by taking the percentage of the Emsworth growth rate which approximates to that at the site under investigation. An indirect approach such as this is clearly less desirable than manipulation of the environmental parameters which directly determine the performance of oysters at the site.

The shortcomings of this model with respect to *O. edulis* are sufficient to render it unsuitable for use in this study in its present form. An investigation of the economics of oyster production under a variety of conditions requires a model which both accurately reflects the performance of oysters in the sea and is sufficiently flexible to permit sensitivity analysis on the results. The author sought to achieve this by utilising the actual growth and mortality data presented by Askew and other workers to pursue two independent modelling approaches.

5.4.2 The von Bertalannfy growth model

In fisheries work the von Bertalannfy equation has been found to have wide applicability. The model is based on the concept that an organism's rate of growth is related to the amount by which its size falls short of an upper asymptotic size. The equation is formulated in terms of length or weight (Gullard, 1969).

$$l_t = L_\infty \left[1 - e^{-k(t-t_o)}\right] \quad .... \quad \text{Eq 5.3}$$

$$\text{or} \quad W_t = W_\infty \left[1 - e^{-k(t-t_o)}\right] \quad .... \quad \text{Eq 5.4}$$

where l_t is the length at time t; W_t is the weight at time t; L_∞ is the asymptotic length at infinite age; W_∞ is the asymptotic weight at infinite age; t_o is the theoretical time for which growth is zero, and K is the rate at which the asymptote is approached in time expressed either as length or weight. These constants are readily evaluated from measurement in length or weight at age.

In this study growth data in terms of weight is used in preference to length data since the latter is more variable and over the upper size range changes little whereas weight increases are still appreciable.

The weight of an organism is usually closely proportional to the cube of its linear dimension:

$$\text{weight} = a \times \text{length}^b \quad .... \qquad \text{Eq 5.5}$$

where b = 3

This approximation to the value of the constant b is often substituted into Equation 5.4. The validity of this assumption was tested for oysters by deriving the precise relationship between weight and length for both species. The derived equations are as follows:

Crassostrea gigas

$$W = 0.0001718 \times L^{2.78} \quad .... \qquad \text{Eq 5.6}$$

based on Walne and Spencer (1971)

Ostrea edulis

$$W = 0.0002037 \times L^{2.97} \quad .... \qquad \text{Eq 5.7}$$

based on Millar (1968)

The approximation to the value of the constant b is acceptable for *O. edulis* but the effect of the elongated, often irregular shell of *C. gigas* is reflected in a lower value for b. In the von Bertalannfy growth equation a value for b of 2.80 is employed for *C. gigas*.

The values for the constants W_∞ and K in Equation 5.4 may be estimated directly from a Ford-Walford Plot. This is a graph of the relationship between size at time t and size at time (t+1). The Ford-Walford Plot is usually expressed in terms of length and to convert weight to an equivalent linear dimension $\sqrt[b]{wt}$ must be employed. The derived functions are illustrated in Figure 5.1. The gradient of the Ford-Walford plot is e^{-k} and the intersection of the function with the 45° axis yields the value of W_∞. The derived Ford-Walford relationships are as follows:

The weight of an organism is usually closely proportional to the cube of its linear dimension:

$$\text{weight} = a \times \text{length}^b \quad \text{..........} \quad \text{Eq 5.5}$$

where b = 3

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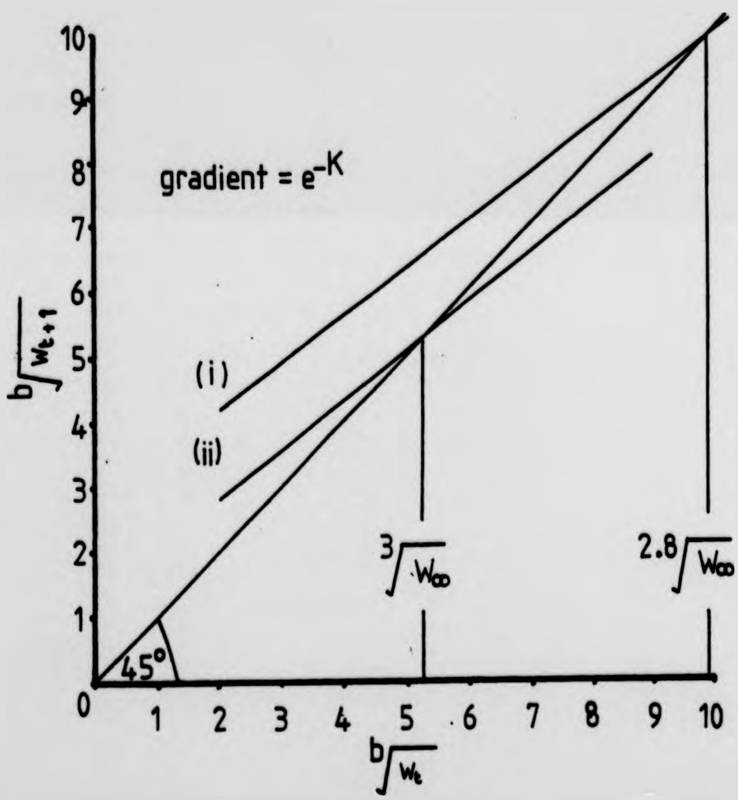
based on Millar (1968)

The approximation to the value of the constant b is acceptable for *O. edulis* but the effect of the elongated, often irregular shell of *C. gigas* is reflected in a lower value for b. In the von Bertalannfy growth equation a value for b of 2.80 is employed for *C. gigas*.

The values for the constants W_∞ and K in Equation 5.4 may be estimated directly from a Ford-Walford Plot. This is a graph of the relationship between size at time t and size at time (t+1). The Ford-Walford Plot is usually expressed in terms of length and to convert weight to an equivalent linear dimension $\sqrt[b]{wt}$ must be employed. The derived functions are illustrated in Figure 5.1. The gradient of the Ford-Walford plot is e^{-k} and the intersection of the function with the 45° axis yields the value of W_∞. The derived Ford-Walford relationships are as follows:

Figure 5.1 The Ford Walford plots derived for oysters



(i) Crassostrea gigas

(ii) Ostrea edulis

Crassostrea gigas

$$2.8\sqrt{W_{t+1}} = 2.6106 + 0.7274 \times 2.8\sqrt{W_t} \quad \ldots\ldots \quad \text{Eq 5.8}$$

Ostrea edulis

$$3.0\sqrt{W_{t+1}} = 1.275 + 0.759 \times 3.0\sqrt{W_t} \quad \ldots\ldots \quad \text{Eq 5.9}$$

Given values for the constant K a value for the theoretical time when growth is zero (t_o) can be computed from:

$$t_o = t + \frac{1}{K} \times \log_e \left(\frac{1-l_t}{l}\right) \quad \text{where } w = a.L^b \text{ is used to estimate L}$$

To summarise, the derived parameters for each von Bertalannfy growth equation are:

Species	Constant			
	b	W_{oo}	K	t_o
C. gigas	2.8	593.4	0.3183	-0.4071
O. edulis	3.0	148.0	0.276	-1.011

The respective von Bertalannfy growth equations become:

C. gigas

$$W_t = 593.4 \left[1-e^{-0.3183(t+0.4071)}\right]^{2.8} \quad \ldots\ldots \quad \text{Eq 5.10}$$

O. edulis

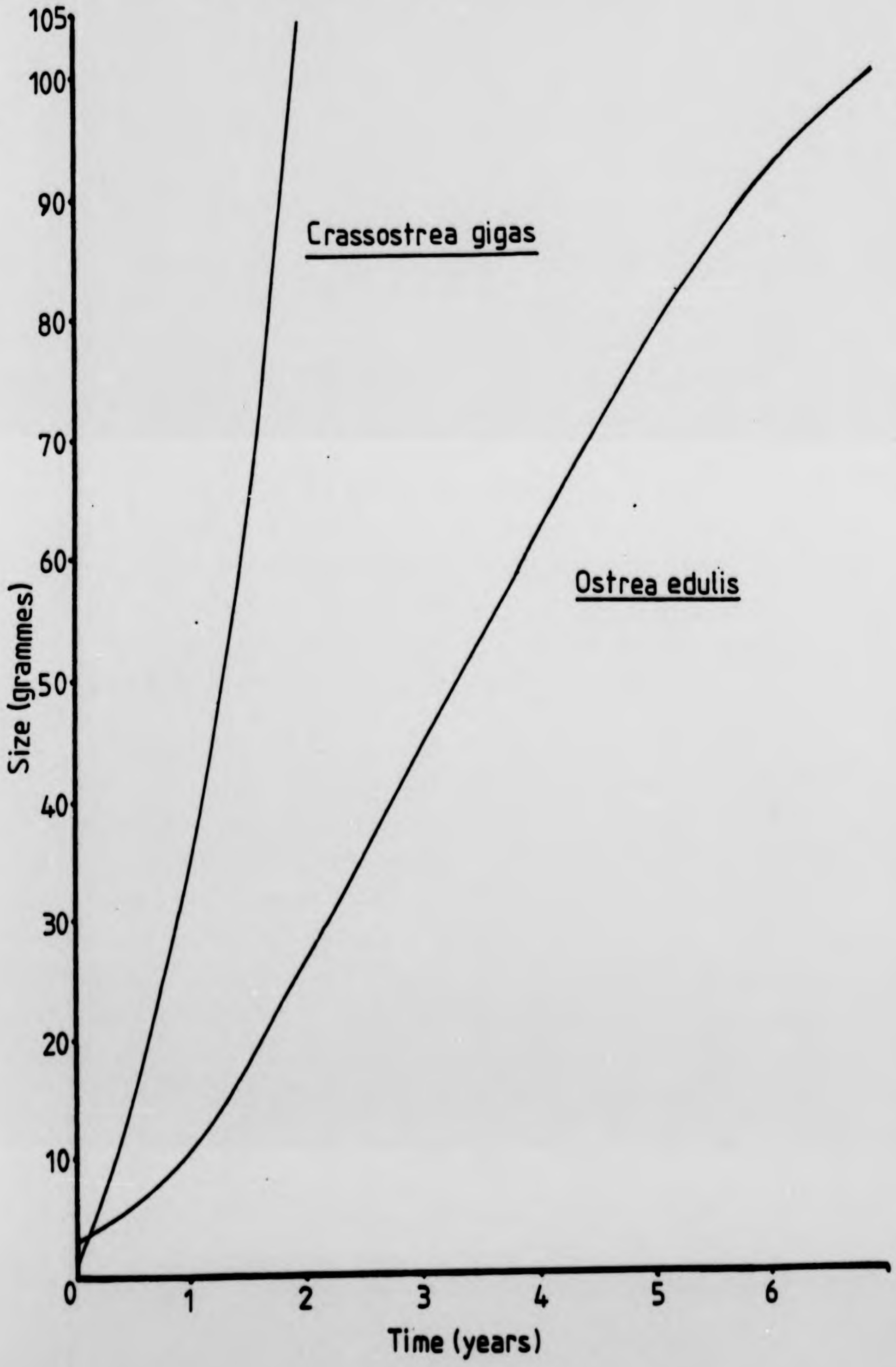
$$W_t = 148.0 \left[1-e^{-0.276(t+1.011)}\right]^{3} \quad \ldots\ldots \quad \text{Eq 5.11}$$

Using these equations it is possible to construct growth curves for each species (Figure 5.2).

To test the utility of this model a computer programme was written using the von Bertalannfy growth equation to generate growth curves and the generalised mortality curves derived by Askew to estimate survival between time periods. In the simulation time periods of $\frac{1}{12}$ years were employed.

It was found that the model could be used to give acceptable estimates of oyster yields for both species. However, there are certain conceptual problems arising from the use of models of this type.

Figure 5.2 Growth curves for oysters as described by the von Bertalannfy equations



Firstly, the value of the constant t_o in both cases is negative. This implies that growth occurs before time zero and is clearly impossible. This effect is particularly marked for *O. edulis* and can be seen in Figure 5.2. The model predicts that for this species growth commences at time - 1 years and that oysters attain a size of 4 grammes by time zero. This is only a theoretical anomaly as the time v size relationship is involved in this range. If the quality of input data for the model were improved this anomaly could be removed.

It is very difficult to conceptualise the meaning of the parameters in the growth equation. They appear to have little biological meaning. This is a criterion for model selection which the author stressed earlier. The model in its present form takes no account of seasonal variation in growth. Attempts to introduce a seasonal growth element superimposed an artificial variation on the growth curve rather than represent parameters which acted as determinants of growth. Survival curves based on similar parameters to those used in the growth equations can be constructed. However, the author considers the von Bertalannfy modelling approach to be too inflexible to employ in the investigation of commercial oyster production.

The proposed model for oyster growth provides a very good illustration of what can be termed smoothed growth patterns. As such they provide a useful tool for comparing on-site growth performance with established growth rates. The model clearly illustrates the difference in growth rates of the two species. The Pacific Oyster only requires 18 months to reach a market size of 70 grammes compared to 4.5 years for *O. edulis.* These differences and the environmental parameters which influence them have obvious economic consequences. In an attempt to account for such effects a second modelling approach proved to be more fruitful.

5.4.3 The multiple regression model

The aim of this model is to include environmental parameters together with size as variables determining growth. Seawater temperature and food availability have been identified as the two main environmental factors controlling growth rate. In view of the problem of quantifying the role of food availability it has not been possible to include it in the regression model. Seawater temperature is considered. The model is based on a simple, multiple regression relating oyster size and seawater temperature to growth rate in the general form:

$$Y = A_o + A_1X_1 + A_2X_2$$

Growth is estimated in the model by using the instantaneous growth rate for 30 day periods (G_{30}). This is the natural logarithm of the ratio of the final weight to initial weight of an organism in a unit of time, in this case, 30 days. Values for G_{30} for different sizes of oyster and at different temperatures have been calculated from several sources. In any food producing system the yield in a given time depends on the balance between the rate of growth of the organism and the mortality suffered. In the model, mortality is described by the relationship between initial weight (W_o) and the 30 day instantaneous mortality coefficient (Z_{30}) as given by Askew (Section 5.4.1). Three levels of mortality are employed: low, medium and high corresponding to Askew's derived mortality function and the 50% confidence limits about it. These relationships are presented in logarithmic form in Figure 5.3.

The derived mortality equations used in the model are:

Low mortality rate

$$Z_{30} = 0.00993 \times W_o^{-0.5446} \quad R^2 = 0.7673 \quad \ldots\ldots \quad \text{Eq 5.12}$$

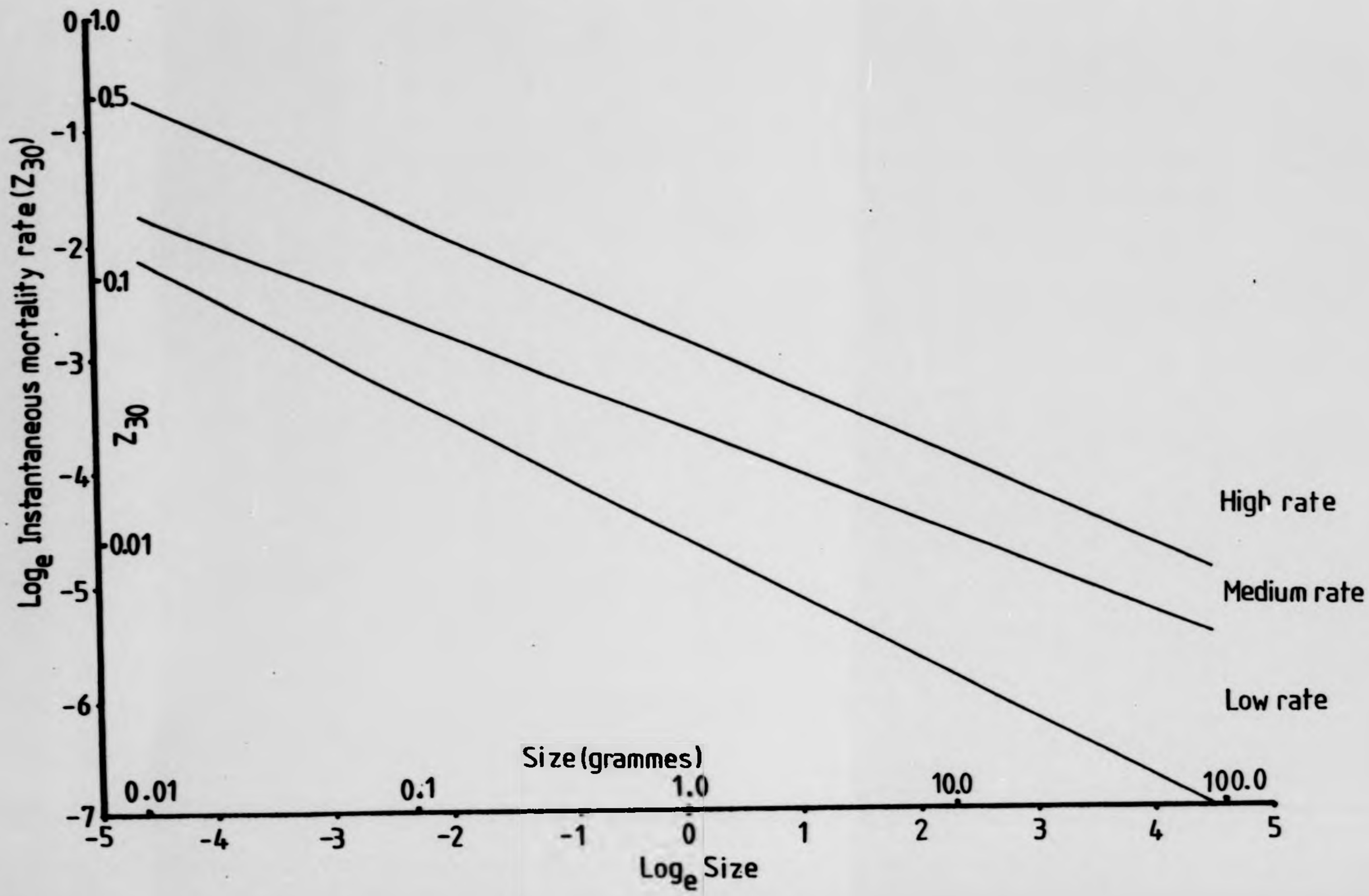
Medium mortality rate

$$Z_{30} = 0.02614 \times W_o^{-0.4154} \quad R^2 = 0.8571 \quad \ldots\ldots \quad \text{Eq 5.13}$$

High mortality rate

$$Z_{30} = 0.05688 \times W_o^{-0.4607} \quad R^2 = 0.860 \quad \ldots\ldots \quad \text{Eq 5.14}$$

Figure 5.3 The relationship between Initial Size and Instantaneous Mortality Rate



The mortality model makes the reasonable assumption that mortality rate declines as oyster size increases. The values of W_o used to estimate the mortality coefficient (Z_{30}) are those generated by the multiple regression model.

An attempt was made to update the mortality function by inclusion of the temperature dependant mortality relationship described for *O. edulis* by Spencer and Gough (ibid). However, the effect of this was found to be negligible due to the small size range over which it was observed and it has been omitted.

The advantage of using instantaneous rates throughout the model is that they can be handled arithmetically. Rates for short periods may be summed to give the long term aggregates and different rates may be compared as direct ratios (Ricker, 1968). The incorporation of instantaneous growth rates into smoothed growth curves in a generalised model is a simplification but it has been shown that the growth rate of oysters in the sea is regular (Walne, 1971). Description of the generalised growth pattern is one of the most practical uses of growth simulation models.

Seawater temperatures closely follow but lag behind air temperatures. The level of solar radiation is the predominant determining factor although the magnitude and timing of its effects also depends on the depth and stratification of the water mass. Year to year variation in seawater temperatures do occur but it has been demonstrated that over long periods over 90% of the total variation may be accounted for by the seasonal cycle (Maddock and Swann, 1977). Diurnal variations with depth and position may occur but their effect is negligible when compared to the overall seasonal pattern. Time units of one month are both convenient to use and yet sufficiently short so as not to mask the effect of season on seawater temperatures. In the model mean monthly surface seawater temperature regimes are employed. Two temperature regimes are considered; Menai Straits, North Wales and Emsworth harbour, Hampshire. Both are proven oyster ongrowing sites for which several years recordings of seawater temperature are available. To avoid year to year fluctuations mean monthly seawater temperatures for each month of the year have been calculated (Table 5.2). Data for *O. edulis* and *C. gigas* relating growth rate to two independant variables were abstracted from observations between 1970 - 1975 at four sites: Langstone and Emsworth harbours (Askew, 1976); Menai Straits and Conwy (Spencer and Gough, 1978).

Published information on oysters describes the relationship between size and growth rate as being non-linear. Similarly over the size range of oysters grown in the sea the effect of temperature on growth rate has been established as non-linear. For the purpose of calculating the regression equations for each species all three variables have been transformed to the logarithmic form (base 10). This was done in an attempt to introduce linearity. Furthermore, transformation to the logarithm will often stabilise the variance by introducing a homogeneity not present in the raw data (Ricker, 1973). This is most useful when observations are concentrated at one end of their frequency distribution or if there are gaps in the distribution. This was found to be the case with suitable published results for oyster growth trials.

Using the data in this form and the multiple regression technique the following growth models were derived:

<u>*C. gigas*</u>

$$\mathrm{Log}_{10}G30 = -2.12828 - \underset{(0.03036)^*}{0.32901}\mathrm{Log}_{10}Wo + \underset{(0.18039)}{1.6767}\mathrm{Log}_{10}Temp \quad \ldots\ldots \quad \text{Eq 5.15}$$

number of observations = 51 $\quad R^2 = 0.859$

<u>*O. edulis*</u>

$$\mathrm{Log}_{10}G30 = -6.44892 - \underset{(0.10341)}{0.55745}\mathrm{Log}_{10}Wo + \underset{(0.50255)}{5.16993}\mathrm{Log}_{10}Temp \quad \ldots\ldots \quad \text{Eq 5.16}$$

number of observations = 54 $\quad R^2 = 0.707$

*standard error of the regression coefficient.

Wo = weight at beginning of the month

Temp = monthly seawater temperature

Table 5.2 Mean monthly surface seawater temperatures at two established oyster cultivation sites: Emsworth Harbour (Hampshire) and Menai Straits (North Wales)

Month	Mean Monthly Seawater Temperature (°C)	
	Emsworth Harbour[1]	Menai Straits[2]
January	6.0	7.0
February	5.3	7.0
March	6.3	8.2
April	10.5	9.2
May	15.0	12.5
June	15.0	15.0
July	18.75	17.2
August	18.5	17.0
September	16.5	15.2
October	14.3	13.1
November	11.0	8.0
December	7.5	7.4

Notes:

1. Based on Askew, C G (1972)
2. Based on Walne, P R (1974)

The Coefficients of Determination (R^2) give a measure of causal association between the dependant variable and the independant variables. In each case the fitted equation shows a significant relationship to be present. However, the value of R^2 does not indicate whether each regression coefficient has a significant effect within the equation. This is an important point since if it is not the case there is no justification for the variable's inclusion in the model.

The most obvious check on the relevance of the regression coefficient is its sign. In both models the equation indicates that an increase in size is associated with a decrease in the rate of growth and that an increase in temperature will, over the range of data used, cause an increase in growth rate. These relationships are presented in Figures 5.4 and 5.5. In all cases the growth rate of *O. edulis* is less than that for *C. gigas* under the same conditions. This agrees with the results of growth studies quoted earlier.

Two methods may be employed to test the significance of the coefficients: the first requires a knowledge of the sampling distribution of the particular sample statistic and its standard error to perform a 'Student's' *t* test. The alternative is to use the analysis of variance technique to compare explained with unexplained variation by means of an F test (Yeoman, 1968). The Null Hypothesis for both tests is that the regression coefficients are not significantly greater than zero. The results obtained from the analysis of variance are summarised in Table 5.3.

With the exception of the coefficient for the size variable in the *O. edulis* equation (which is significant at the 5% level) all the results were found to be significant at the 1% level. In each case, therefore, the null hypothesis must be rejected since the inclusion of each regression coefficient significantly increases the total amount of variation explained by the model. The results of 'Student's' *t* tests are not shown but similarly show a significant relationship in each case.

It can be seen from the model equations (Eq 5.15 and 5.16) that in the case of *O. edulis* the standard error of the regression

Figure 5.4 The relationship between Oyster Size and Instantaneous Growth Rate at standardised seawater temperatures

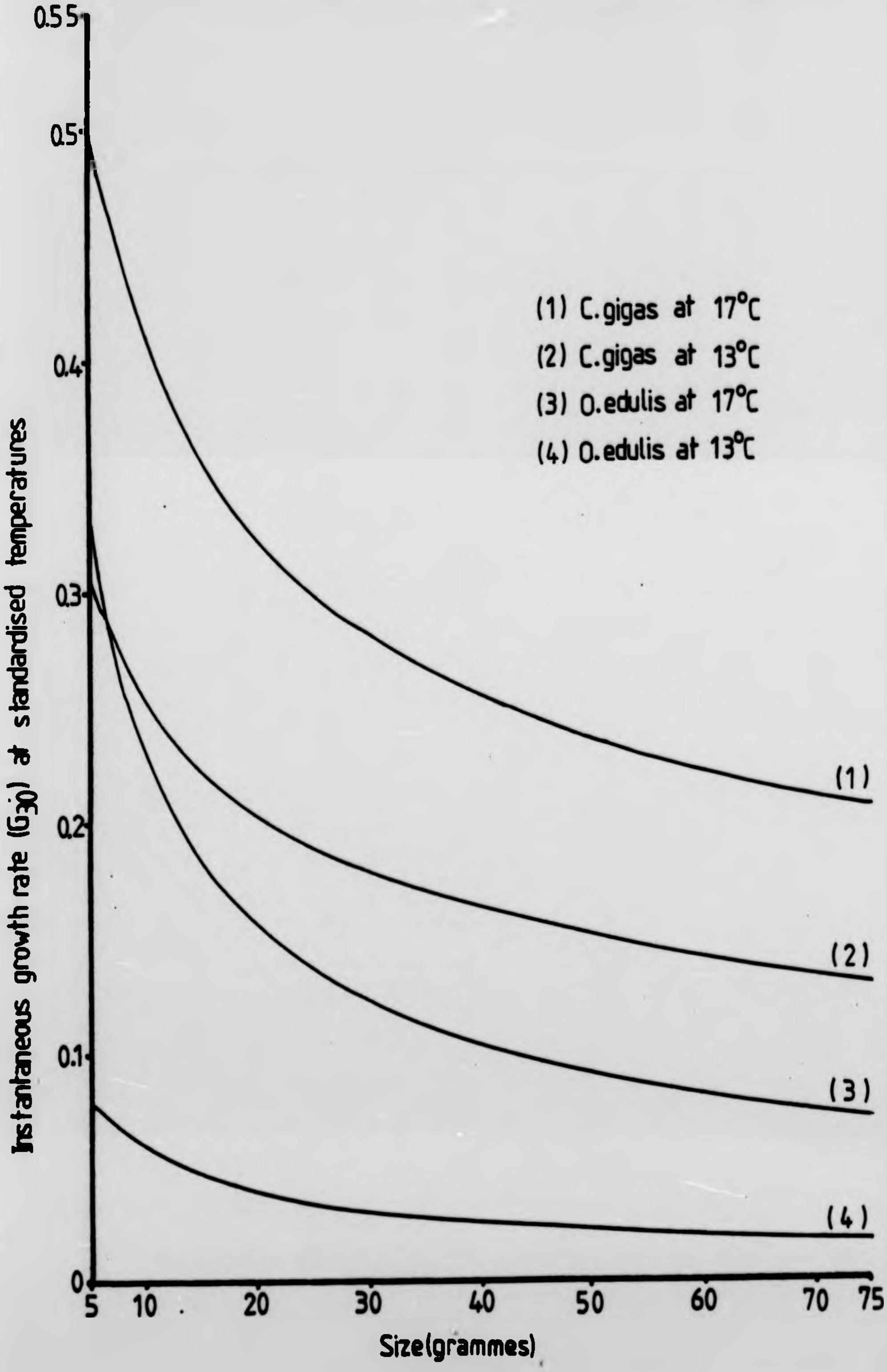


Figure 5.4 The relationship between Oyster Size and Instantaneous Growth Rate at standardised seawater temperatures

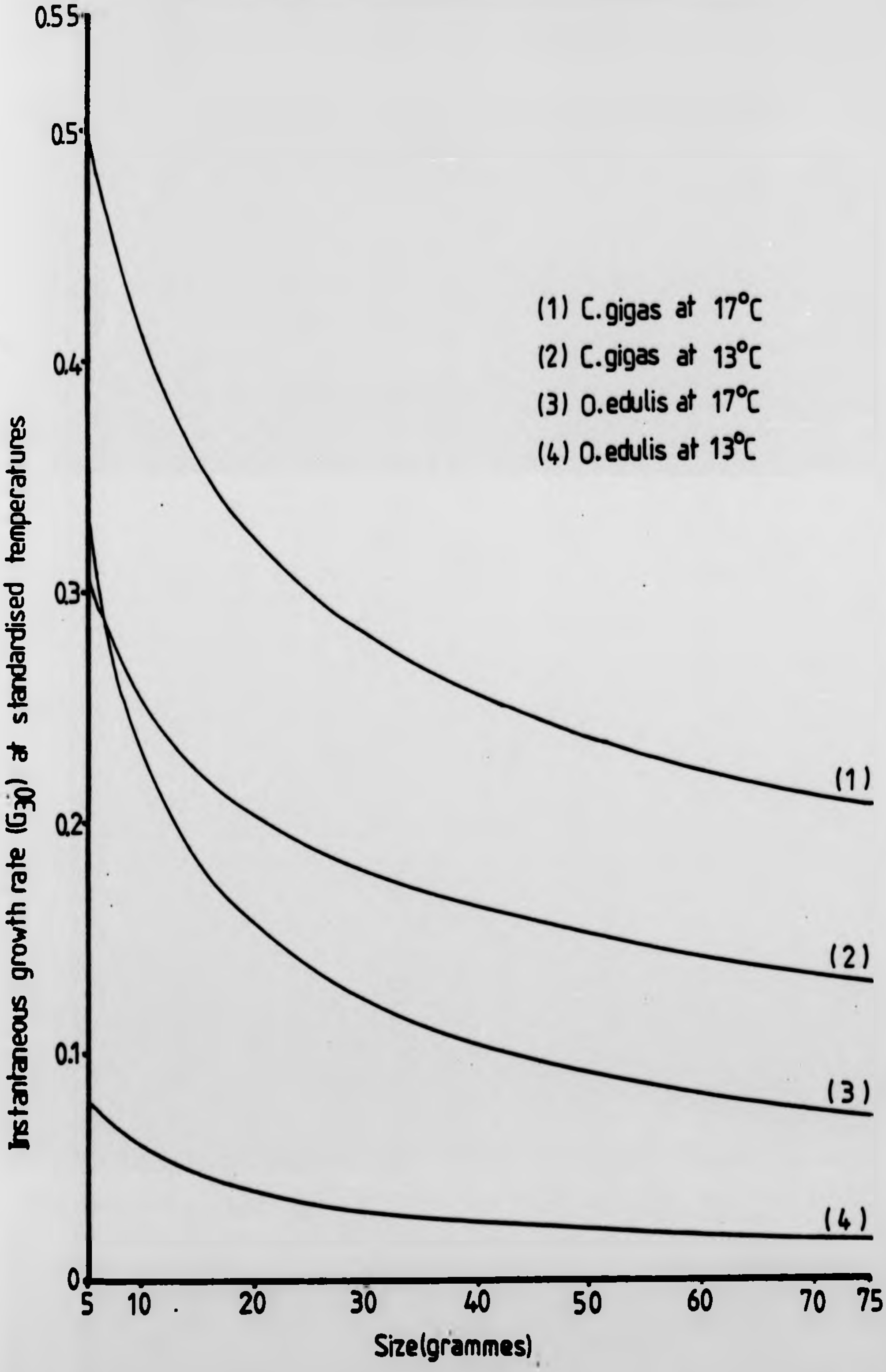


Figure 5.5 The relationship between Seawater Temperature and Instantaneous Growth Rate for oysters standardised to a size of five grammes

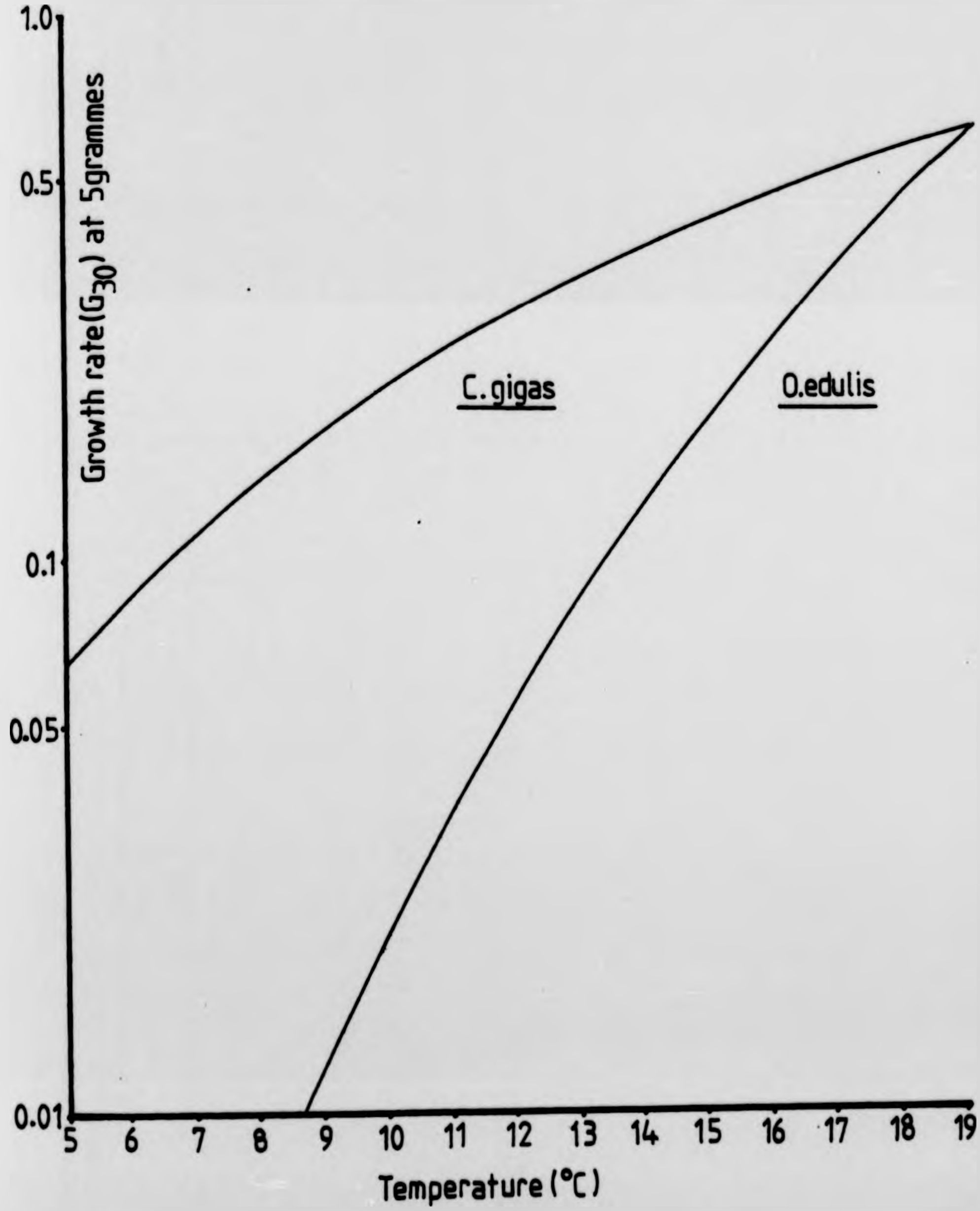


Table 5.3 Analysis of variance to determine the significance of the regression coefficients

Species	Source of Variance	Degrees of freedom	F ratio (calc.)	F ratio (tables)	(d.f.)	Comment
C. gigas	Regression	2,48	146.159	5.110	(2,45)	Significant at 1% level
	W_o coeff.	1,49	75.073	7.234	(1,45)	Significant at 1% level
	TEMP coeff.	1,49	51.682	7.234	(1,45)	Significant at 1% level
O. edulis	Regression	2,51	61.609	5.057	(2,50)	Significant at 1% level
	W_o coeff.	1,52	5.735	4.034	(1,50)	Significant at 5% level
	TEMP coeff.	1,52	60,980	4,034	(1,50)	Significant at 1% level

coefficients are quite large relative to the values of the coefficients. This is an indication of the presence of multi-collinearity in the data; the existence of an imperfect linear relationship between independant variables (Mayer and Mayer, 1976). To determine the extent of this effect the simple correlation coefficients between the two independant variables were determined and found to be 0.12279 for *O. edulis* and -0.30455 for *C. gigas*. In both cases the values are small and whilst indicating some multicollinearity in neither case is the relationship significant. To some extent this is to be expected since both variables attempt to consider variation due to sources not included in the model. This effect can only be totally removed by the inclusion of all variables which determine growth (clearly infeasible). The addition of further data may reduce this effect but even with the present models it appears that the degree of correlation between the independant variables is not significant and should not unduly impair the utility of the equations for predicting growth patterns.

The statistical analysis confirms that the derived multiple regression equations give a good fit to the data. It is possible to construct a model based on these functions and the mortality equation which will predict oyster yields under any temperature regime.

The model uses the initial weight and initial month's seawater temperature to compute, using the appropriate growth equation, the instantaneous growth rate for the month (G_{30}). This value is then used to calculate the weight achieved by the end of the month from equation 5.1. This forms the initial weight for the next time period and using the corresponding monthly seawater temperature the procedure is repeated. The reiterative process continues using discreet time intervals of one month until the predetermined maximum size is reached. The predicted weights are taken to be the average weight of all oysters in the batch. Mortality is calculated from the value of W_o each month and the appropriate instantaneous mortality coefficients (Z_{30}) as described earlier in this section.

To facilitate manipulation of this model a computer programme (Fortran IV) has been written. The required input data is: species, initial spat weight (grammes) and number, desired mortality rate, month laid out and temperature regime to be used. A programme listing and an example of the output are given in Appendix II. The main steps in the computations involved in the programme are summarised in the flow chart (Appendix II).

Examples of predicted growth curves produced by this model are given (Figures 5.6 - 5.9). In each case the initial condition employed was 0.1 gramme spat laid out in the sea in April - June. Programme runs were performed using these conditions for each species at the two temperature regimes considered in this analysis. The graphs illustrate the much shorter ongrowing period of *C. gigas* compared to *O. edulis* and the predicted results show good agreement to growth rates quoted earlier. The step-like form of the graphs reflect the seasonal nature of growth. The horizontal phases represent winter when little or no growth occurs. The presence of some winter growth in *C. gigas* is shown by the slight increase in size over the winter months (Figure 5.6). The gradient of the upward sections of the graphs decreases over time indicating that the relative growth rate of oysters is greatest when the oysters are small. The effect of site on growth rate is evident in all figures. The site with the higher temperature regime yields a faster growth rate. The difference in growth with *C. gigas* is only one or two months but for the more slow growing *O. edulis* the choice of site can result in nearly two years difference in ongrowing time. The significance of this for commercial operators can be readily appreciated. These two temperature regimes represent the range of ongrowing rates which may be encountered in commercial ventures. By changing the month laid out, spat size, temperature or mortality rate any commercial situation may be simulated using this model. As an independent check on the model a temperature regime recorded at Loch Sween, Scotland, was employed in the model. The predicted growth rates were 17-22 months for *C. gigas* and 5-5½ years for *O. edulis* , values which show good agreement with growth rates given in Table 5.1 for Scotland.

One restriction must be placed on the model's use. Very little data is available regarding the growth of oysters at high temperatures. The regression relationships have been found to give acceptable results for both species over the temperature range employed to construct the model and for higher temperatures for *C. gigas*. Extrapolation to temperatures beyond the range of data used yields growth rates for *O. edulis* which are higher than those for similar sized *C. gigas* (Figure 5.5). No published information supports this and it is undoubtedly the result of the scarcity of data at high temperatures. Extrapolation to temperatures greater than those used in this study is invalid for *O. edulis*. The effect of this constraint on the performance of the model is not believed to be significant. Temperatures rarely exceed this range for more than a few days and their effect is minimised by the use of monthly seawater temperatures. In the future information on the growth and survival of *O. edulis* at high temperatures may be provided by nursery operations utilising heated seawater and this may be used to update the model.

5.5 SUMMARY

There are a wide range of factors which determine the performance of oysters in the sea. The employment of models offers a fruitful approach to studying the important parameters. Existing models have been shown to be of limited value in the simulation of the growth performance of *O. edulis*. From the commercial standpoint this species is of prime interest since its slow growth rate is offset by a selling price almost double that which *C. gigas* can command.

The author has developed two original models which describe the growth patterns of both species of oyster. The first approach is based on the von Bertalannfy growth equation but is considered too inflexible for use in a comprehensive appraisal of commercial oyster production. A second model has been developed based on the multiple regression technique. This approach has yielded functions which take account of both oyster size and seawater temperature as determinants of oyster growth rate. This model utilises a simple equation the parameters of which are biologically meaningful and lend themsleves to sensitivity analysis. Statistical tests have confirmed that the model may be used to simulate the growth and mortality of both species of oyster under a range of conditions.

Subsequent chapters consider the economics of oyster culture. The multiple regression model is used in this investigation to establish the effects of season, oyster performance and site on the economics of different techniques of oyster culture and on the scheduling of production.

Figure 5.6 <u>Predicted growth curves for 0.1 gramme spat of *Crassostrea gigas* laid out at Emsworth in three batches, April - June</u>

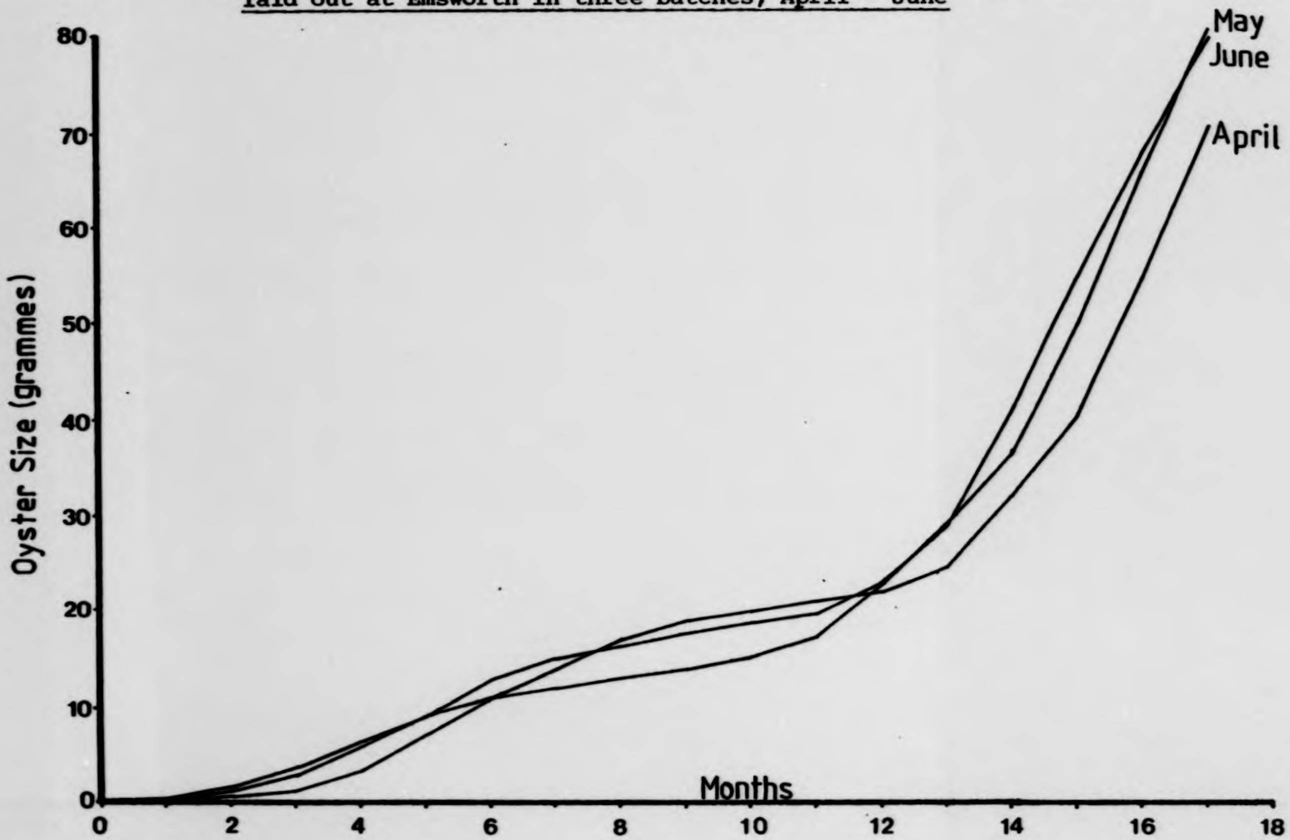


Figure 5.7 Predicted growth curves for 0.1 gramme spat of *Crassostrea gigas* laid out at Menai in three batches, April - June

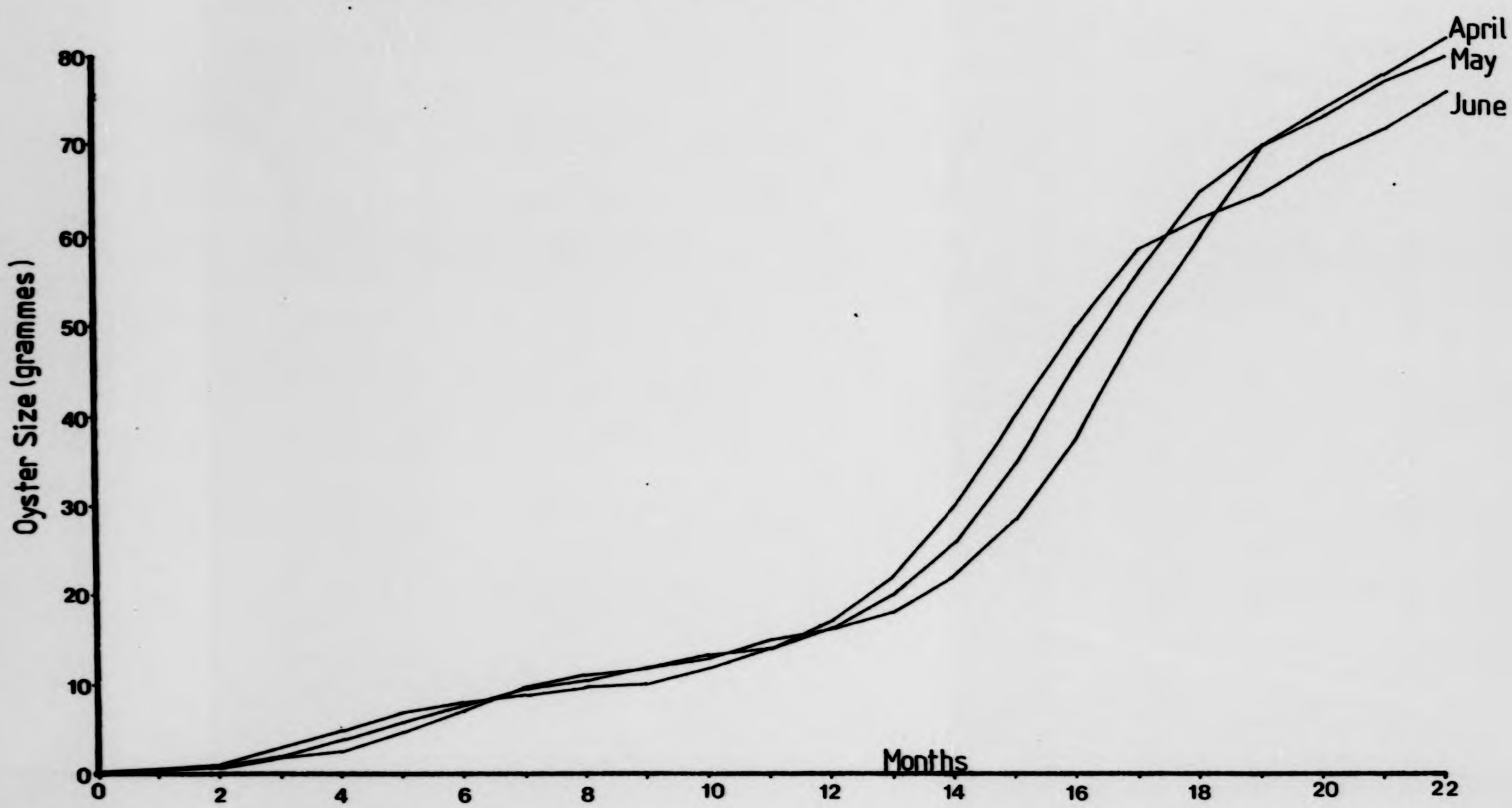


Figure 5.8 <u>Predicted growth curves for 0.1 gramme spat of *Ostrea edulis* laid out at Emsworth in three batches, April - June</u>

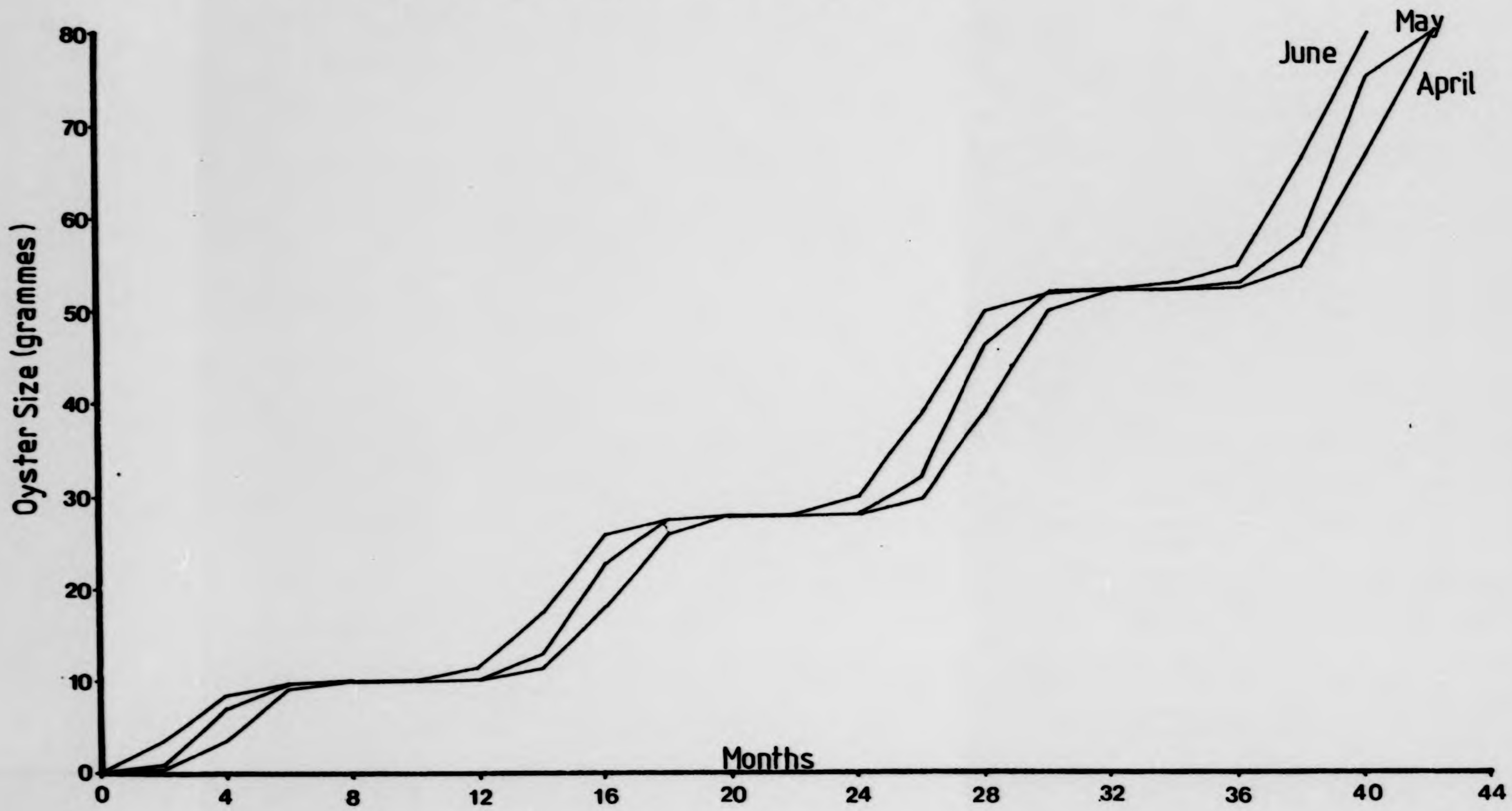
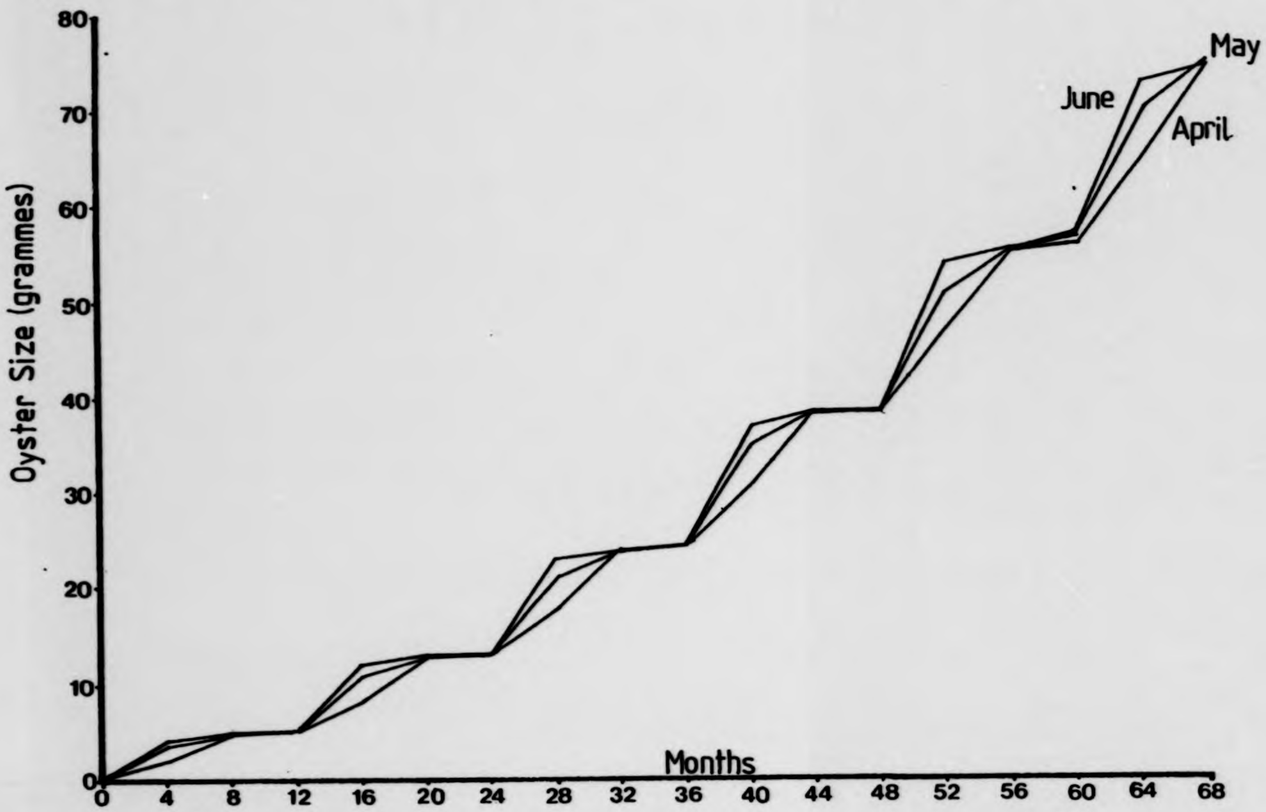


Figure 5.9 **Predicted growth curves for 0.1 gramme spat of *Ostrea edulis* laid out at Menai in three batches, April - June**



Chapter 6

COMMERCIAL ASPECTS OF OYSTER CULTURE

6.1 BACKGROUND

Recent years have witnessed rapid technical advances in the field of aquaculture such that the commercial cultivation of many species is now feasible and in some cases a reality. However, this development has not been matched by economic investigation of such systems and to date the problem of economic feasibility has only tentatively been approached. Several authors have estimated costs and revenue from utilising different techniques or designs for oyster cultivation (Briggs, 1978; Spencer and Gough, ibid) but have not projected their economic analysis over a sufficient time period. Notable exceptions are the work of Varley (1977) and Hails (1978) on trout production in the United Kingdom, and Askew (1976) on the economics of oyster production. In each case the author has attempted to look at cash flows over several years and has employed Discounted Cash Flow techniques to give all values a common basis.

Economic investigation of fish farm operations using basic cost data is essential both to assess the efficiency of operations and to provide the basis for entrepreneurial decisions (Berge, 1976). The quality of the basic input and output data has a pronounced effect upon the projected cash flows. It is essential in any appraisal to explicitly state assumptions and costs taken and where possible carry out sensitivity analysis to determine the effect of any changes in these factors. The employment of simple economic techniques such as discounted cash flows allows consideration of the timing as well as the magnitude of cash flows by bringing all figures to a common base year. This is crucial since the cost of capital invested at the present is greater than that of the same capital invested at some date in the future (the sum to be spent at a later date could be invested now and earn interest until the time it is required).

Two methods are used to discount cash flows, Internal Rate of

Return (IRR) and Net Present Value (NPV), which are closely related and supplement each other. The IRR is the rate of return which discounts the net cash income of a project to a present value amount equal to its capital cost. This method does not indicate anything concerning the amount invested or recovered during the project but has the advantage of being a single figure upon which alternative projects can be initially compared.

The NPV is the present value of the project's net cash flow discounted at the company's cost of capital at the time of the initial capital outlay minus the initial capital outlay. This method takes account of the whole duration of the project, the size of the investment, depreciation and the cash flows. The choice of an appropriate rate of discount is a problem which is discussed later.

The marine environment is much more demanding than onshore conditions and certain authors have suggested that the use of standard accounting conventions for aquaculture may not truly reflect practical working conditions (Lewis, 1979; Secretan, 1979). Risks and uncertainty in fish farming are largely associated with the quality of husbandry and environmental factors which are generally unquantifiable and in the latter case out of the operators' hands. Past studies have attempted to solve this problem by the inclusion of a contingency allowance but such an approach does not help in identifying risks or their effects. Throughout this analysis the approach adopted will be to use sensitivity analysis on major cost and environmental factors to assess the sensitivity of profits to these changes.

The information contained in this chapter, it is hoped, provides a complete set of costs taken in mid 1979 upon which economic appraisals of different types of oyster culture and scales of operation can be investigated. The generalised growth and mortality model described earlier will be used to predict stock performance under varying environmental conditions and the derived stock value will be incorporated into the economic model as revenue. The objective of this study is to cost out different systems and to identify and investigate the sensitivity of profitability to changes in the main cost centres. It is hoped that the information gathered will provide an accurate picture of the economics of oyster cultivation, and act as a basis for the improvement of management decisions.

The analysis is only intended to present average capital and operating costs and as such should not be considered as in situ studies since specific site, technical and managerial factors will differ markedly between enterprises.

6.2 OYSTER PRICES

6.2.1 Oyster spat

The ex-hatchery price lists of the major shellfish hatcheries in the United Kingdom were used to derive average oyster spat prices for 1979. An exponential function was found to give the best fit to data relating spat size (grammes) and price (£/100 spat). The derived equations are used to establish the cost of buying in oyster spat in each appraisal. Spat price curves derived from these expressions are shown in Figure 6.1.

C. gigas Price $= 13.668 \times \text{Size}^{0.2538}$ ..... Eq 6.1

$n = 22$ $R^2 = 0.962$ Standard error of regression coefficient = 0.0482

O. edulis Price $= 17.05 \times \text{Size}^{0.2652}$ ..... Eq 6.2

$n = 20$ $R^2 = 0.90$ Standard error = 0.0540

6.2.2 Mature oysters

Oysters for human consumption are sold by grades based principally on size. The sale of *O. edulis* is seasonal and to derive sale prices appropriate to mid 1979 it has been necessary to employ the average of the 1978/79 and 1979/80 prices. Price data for *O. edulis* was supplied by Billingsgate Wholesale Fish Market and for *C. gigas* prices are the average of prices from several ongrowers. The values used in this model are:

Figure 6.1 Derived 1979 price curves for ex-hatchery oyster spat

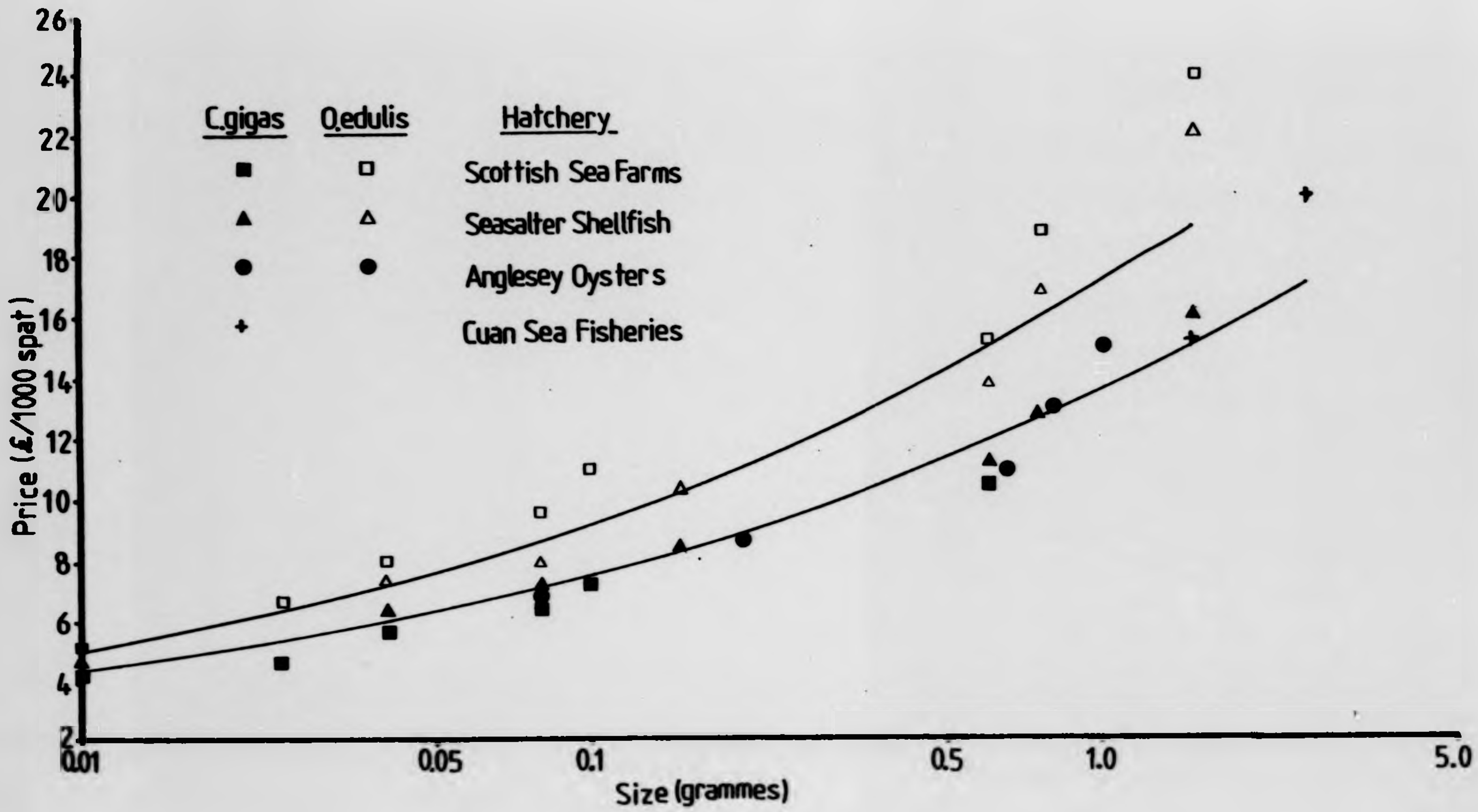


Table 6.1

Species	Marketable range				
C. gigas					
Size (g)	50 - 74.9		75g +		
Price (£/1,000)	110		150		
O. edulis					
Grade	5	4	3	2	1
Size (g)	40-49.9	50-59.9	60-69.9	70-79.9	80+
Price (£/1,000)	160	185	230	260	300

The use of a grading system for oysters is discussed in Chapter Eight. In the investment appraisals it is assumed that all cultured oysters are ready for market at a size of 70 grammes or over.

Oysters between the size ranges of spat and mature oysters are not considered since no market currently exists for them. Interpolation of the quoted prices to include this size range is not valid . Most of the data would be concentrated at one end of the distribution. Furthermore a realistic valuation of such stock should be based on the cost to produce it rather than the value of other size ranges.

6.3 THE COST OF ONGROWING EQUIPMENT

A description of the various types of tray, bag and nets suitable for both the intertidal and suspended culture of oysters has been given in Chapter Three. The cost of each design per m^2 growing area together with the cost of frames or buoyancy required is given in Table 6.2. In the economic appraisal the effect of using alternative designs on the economics of oyster production is investigated.

Table 6.2 The cost of different systems for the ongrowing of oysters

Type	Growing Area per unit (m^2)	Expected Life (years)	Cost (£) per per m^2 area	Additional requirements	Cost (£)	Total Cost per m^2 area
Wooden trays	0.5	2 - 3	4.00	Trestle and tray tops (20 trays)	30.00	£ 7.00
NWP trays	0.25	5	4.50	Frame and Empty Tray/ Stack	14.35	12.70
Knapdale trays	0.56	10	32.16	None	-	32.16
Oyster bags	0.50	5	2.08	Trestle/ 20 bags	25.00	4.58
Lantern nets	1.30	5	5.08	Buoy (27 kilo)	8.20	11.39
Rafts (to hold 15 stacks of 20 trays)	0.25 (NWP trays)	5	4.50	Raft with Lifting gear	3,100.00	14.57

An alternative to holding units is to ongrow the oysters on beds protected by a fenced enclosure. The construction of such an enclosure is estimated as £3.74 per metre fencing. This has been calculated as follows:

Item	Cost per metre fencing (£)
Excavation to an average depth of 15 cm[1]	£ 0.77
'Netlon' plastic mesh fencing	1.10
Support rods (12 mm mild steel)	0.19
Lip for fence top (15 - 20 cm)	0.55
Wire to bind fence to supports	0.25
Labour to erect fence[2]	0.88
TOTAL COST	£ 3.74 per metre

Notes

1. Cost taken from 'Building' (6 July 1979) for surface soil excavation.
2. Estimated as two metres of fencing erected per hour with labour costed at £1.75 per hour.

Throughout the subsequent analysis the following oyster stocking densities will be used to calculate the requirement for holding facilities:

Table 6.3

Oyster size range (g)	Stocking density (g/cm^2)	Type of culture
0.5	0.2	Tray
0.5 - 1.25	0.2 - 0.5	Tray
1.25 - 10.0	0.5	Tray or Oyster bag
>10.0	0.5 - 1.0	Oyster bed

6.4 SITE SURVEY AND PILOT GROWTH TRIALS

The potential of any site for any type of aquaculture should be fully investigated at the earliest possible stage. Some prospective ongrowers will conduct their own site evaluation but in the appraisal the cost of an on-site investigation by a professional fish-farm consultant will be included. A one to two day on-site investigation with a further two to three days for writing a report was quoted as costing £350 plus expenses[1]. Allowing £100 for expenses this gives a total cost of £450. This inclusion is justified since even if professional services are not employed there will be some cost in both time and money associated with the ongrower's own appraisal. Furthermore institutions offering financial assistance or insurance may stipulate that a detailed site survey be carried out be an impartial individual or company. In such an instance the cost of a survey would be inescapable.

It is not possible to establish the growth potential of a site from a two day survey. This requires growth trials over a period of preferably at least 18 months. In an attempt to include the cost of pilot growth trials the cost of purchasing and cultivating a small batch of oysters may be included in the year prior to the main capital outlay (Table 6.4).

Table 6.4 Cost of Pilot growth trials

Item	Cost (£)
Rent for the site	£ 100.00
Oyster spat (15,000 at 0.1g)	114.30
Trays and Oyster bags[a]	83.00
Labour[b]	157.50
TOTAL COST	£ 454.80

Notes:

a. Includes 16 wooden trays, 20 oyster bags and 1 trestle type frame

b. 15 visits to service oysters assumed, each visit 4 hours servicing plus 2 hours travelling. Labour costed at £1.75 per hour.

1. Figure supplied by Welbeck Aquaculture Limited.

On the basis of the figures given the total cost of site evaluation is approximately £900, all of which is assumed to be incurred at the same time as the bulk of the capital investment.

6.5 LABOUR INPUTS AND COSTS

By comparison with the commercial farming of finfish the culture of bivalve molluscs in the United Kingdom constitutes small, labour intensive units employing relatively unsophisticated growing techniques.

Activities for the ongrower follow a roughly seasonal pattern. Spat are normally bought in from the hatchery in Spring. Throughout Summer and Autumn oysters are regularly regraded and thinned out. Marketing of mature oysters for human consumption occurs mainly in the traditional oyster season of September to April although *C. gigas* may be sold throughout the year.

In some instances it is possible to establish the labour requirements of certain aspects of cultivation. The amount of time available for maintenance of stock and harvesting intertidally laid oysters depends upon the site and the times of low water. The best position for intertidal trays is near Low Water Spring Tide Level where oysters are only exposed to air a few hours each Spring Tide. Normally however, trays will be sited such that they are accessible for 2 - 3 hours at low tide on most tidal cycles. An ongrower is unlikely to be able to utilise both diurnal tidal cycles hence the time intertidal oysters are directly accessible may be as little as three hours per day. The time required for checking and regrading tray cultured oysters has been estimated as 0.2 - 0.3 man-hours per tray (Spencer, 1978). On the basis of this figure it should be possible to service approximately 2,500 1 gramme oysters per tide.

It is estimated that one man working full-time can cultivate approximately 100,000 - 200,000 oysters in various stages of growth and that two full-time workers could tend up to 500,000 growing oysters. In this study the author has adopted the conservative estimate that one full-time ongrower could manage a stock of 100,000 ongrowing oysters.

During the main oyster season an ongrower will spend usually one day per week delivering oysters to his customers and the two previous days tending, harvesting and preparing oysters for market. When the farm is developing towards its target capacity the ongrower will spend the rest of his time developing his system, market or in a part-time occupation to supplement his income.

At present there are no reliable estimates for the labour input requirements of harvesting, cleaning or packing mature oysters. In view of this and the lack of a regular working schedule it is impractical to attempt to allocate labour costs on an activity basis.

An attempt is made to separate out the cost of labour for construction of the oyster farm but the operating labour cost is assumed to be fixed at a standard wage rate.

The workforce involved in fish farming is currently too small to justify a specific scale of wage rates and at present most employers use Agricultural Wage Board Rates of Pay as a yardstick (National Farmers Union, 1979). In the analysis it will be assumed that an oyster-farm worker is the equivalent of an agricultural stockman and his labour will be costed at £70.00 per week. This figure is the estimated average weekly earnings of a stockworker in 1979 as given by Nix (1978). This takes account of both the average earnings, which are in general £5 to £6 per week above the minimum rates published by the Agricultural Wages Boards, and also includes an allowance for some overtime working (Table 6.5).

Table 6.5 Estimated average earnings of Agricultural Workers for 1979

Type of Worker	Average Total Earnings (£)		Total hours per week
	Annual	Per week	
All hired men	3,565	68.55	46.6
Foremen	4,175	80.25	46.3
Dairy Cowmen	4,265	82.00	52.6
Other Stockmen	3,660	70.35	46.9
Tractor Drivers	3,605	69.30	47.5
General Farm Workers	3,325	63.95	45.4
Horticultural Workers	3,290	63.30	43,5
Other Farm Workers	3,590	69.00	45.4

From Nix (1978).

This author also estimated the total number of labour hours available for agricultural field work taking into account seasonal variation as 1,963 hours per annum. This figure shows very good agreement with a labour input estimate of 2,000 man-hours per employee per year given for Norwegian trout farm workers (Berge, ibid). This close correlation between agricultural and fish farm labour inputs and costs suggests that the former may be used with some confidence as an approximation to the cost of labour for oyster culture.

Two further points with regard to labour are relevant to this section. Firstly in a large ongrowing enterprise a manager may be employed. Experience of shellfish hatcheries suggests that this position will be held by a biology graduate with some years relevant experience. To date few ongrowing units are sufficiently large to justify such a post and unless specifically stated all labour will be costed on the basis given above .

Secondly there is a problem when attempting to cost the real value of the labour of an owner/operator. Often such individuals will work long, irregular hours yet will only take a minimal monetary remuneration for his efforts. In a recent paper

Anderson (1980) argues that in the fishing industry there exist non-monetary benefits which the individual receives for participating. Such incentives, which Anderson calles Work Satisfaction Bonus (WSB) are based on the premise that employment in fishing provides satisfaction from such factors as independence, risk taking, tradition etc. Benefits of this nature are undoubtedly present and recognised in fish farming and as such constitute an element in the individual's valuation of his real wage rate. Although it is essential to recognise the existence of WSB it is not possible at present to quantify these benefits. In evaluating alternative projects the owner/operator will be classed as an employee and his labour costed appropriately.

6.6 TRANSPORTATION AND FREIGHT CHARGES

The capital and running costs of operating a vehicle suitable for both general usage and distribution has been included in the appraisal. The cost of delivering oysters to market by freight has also been estimated.

The costs of purchasing and running three different sizes of motor vehicle are shown in Table 6.6. The figures are based on the motor transport cost tables compiled by the trade newspaper 'Motor Transport' for the post-budget quarter ending June 1979.

In each case the vehicle costed has a petrol engine and is written off over a period of four years.

Virtually all oyster cultivators deliver their own oysters to market and the best size of van for this and general usage is the 22 cwt van. Large enterprises marketing several 100,000 mature oysters per annum may require a second vehicle of either the 10 cwt or 35 cwt class depending on its use.

Table 6.6 Cost breakdown for Motor Vehicles

Item	Size of Vehicle		
	10 cwt	22 cwt	35 cwt
(a) Capital Costs			
Purchase Price less tyres	£2,860	£ 3,028	£4,426
Tyres & Spare	89	137	187
(b) Running Costs (pence/mile)			
Fuel[a]	3.72 p	4.227p	5.813p
Oil	0.108	0.116	0.123
Tyres[b]	0.297	0.457	0.620
Maintenance	4.534	6.098	8.136
Total	8.659p	10.898p	14.692p
(c) Standard Costs per annum			
Vehicle insurance	£ 184	£ 201	£ 243
Licences	56	70	84
Depreciation[c]	715	757	1,107
Total	£ 955	£1,028	£1,434
(d) Total charge per mile (Annual mileage)			
5,000	27.76p	31.46p	43.37p
10,000	18.21	21.18	29.03
12,000	16.62	19.46	26.64
15,000	15.03	17.75	24.25
20,000	13.43	16.04	21.86

Notes:

a. Petrol at 93p per gallon.

b. Tyre life in all cases 30,000 miles.

c. Straight line depreciation used on vehicles cost less tyres.

British Rail will accept live shellfish as freight and no special packaging arrangements are necessary. In view of the possibility of deterioration during transit and the obligations placed on the conveyor by the Transit of Animals (General) Order 1973, live shellfish are almost all conveyed by passenger train services and subject to the highest freight rate with owner risk conditions. The following gives two examples of the freight cost of transporting 1,000 mature oysters by rail from West Scotland to wholesale markets in Manchester and London.

Journey	Freight Cost (£) 1978
Fort William to Manchester	£ 13.41
Fort William to London	£ 17.76

If similar orders were despatched each week rail transit would add approximately £800 p.a. at 1979 prices to the cost of distribution.

Freight charges on ferry services between Ireland or the Western Isles and the United Kingdom mainland are even more expensive. Prices quoted varied between £20 - £30 per tonne which corresponds to about 0.16p per oyster carried.

It will be assumed throughout this investigation that farms market the majority of their mature oysters locally and use only motor transport for all deliveries.

6.7 BUILDINGS

An individual operator may be able to administer his business from his home but will still require a store for equipment and a site for a purification plant.

In view of this the cost of a prefabricated building unit of floor area 15 m^2 (6m x 2.5m) subdivided into two internal rooms and a central washing area will be included. Extra units may be added as demand dictates and if sited near the oyster grounds the premises will benefit from classification as farm buildings. The cost of the unit described above including delivery and erection, in 1979, is £2,000 and will be written off over a period of ten years.

6.8 THE PURIFICATION OF OYSTERS

Bivalve molluscs are filter feeders, removing small particulate matter from the seawater as it passes over their gills. Any bacteria of faecal origin including possible pathogens to man may be ingested and accumulated. The degree of pollution which molluscs acquire depends on both the level of pollutants present and upon the level of feeding activity of the shellfish themselves. The objective of purification is to ensure that possible pathogens are either removed or present only in numbers that will not have any debilitating effects.

Sanitary controls for molluscan shellfish are not laid down by law in Britain but current public health standards are quite strict. The basis of control is the use of *E. coli* as a bacterial indicator organism which is both easily enumerated by simple techniques and specific (ie only normally present when pathogenic organisms are present). Shellfish samples are accepted if they contain up to 200 *E. coli*/100 mls sample with occasional samples in the 200 - 500 *E. coli*/100 mls range (Wood, 1972). Shellfish of an unsatisfactory quality for human consumption may be seized and further sales stopped under Section 9 of the Food and Drugs Act, 1955, or the Sea Fisheries (Shellfish) Act, 1967.

In England and Wales the majority of marketable oysters are subjected to a purification process irrespective of whether they come from a polluted area or not. In Northern Ireland all oysters must be purified prior to marketing for human consumption. In Scotland in 1979 no ongrower, to the author's knowledge, used any intensive purification process.

Several methods may be used to purify oysters: relaying in an unpolluted area is the simplest method but requires a period of at least two weeks to ensure that all oysters have an opportunity to purge themselves. Heat treatment using boiling water or steam is unsuitable for molluscs eaten raw since it opens and separates the meat from the shell and if not timed correctly may part-cook the oyster.

For many years the Dodgson system was used to purify Portuguese Oysters at Brightlingsea using low concentrations of chlorine in the seawater supply as a sterilising agent (Wood, 1969). Although successful, this system is not convenient to operate particularly on a small scale. Ozone has also been tested as a sterilising agent but suffers from similar disadvantages to the Dodgson method and if used in concentrations above the minimum required it can weaken or even kill the oyster.

The most widely used system in the United Kingdom employs ultra-violet light to sterilise the seawater. This method is simple to handle, non-toxic to shellfish and leaves no off-flavour in the water. In some cases purification with ultra-violet light has allowed exploitation of shellfish stocks from areas known to be polluted by sewage, including some which have been closed or retricted under the Public Health (Shellfish) Regulation, 1934. At present there are approximately 25 commercial oyster purification plants using ultra-violet light in Britain (Trapper, 1979).

The basic purification plant design is a closed recirculating system where oysters are held in seawater for at least 36 hours during which time the circulating water is subjected to ultra-violet irradiation. Treatment of both *O. edulis* and *C. gigas* is effective at seawater temperatures above 5°C so that little supplementary heating is required even in winter. For the hard clam, *Mercenaria mercenaria* , which 'hibernates' below 10°C purification must be carried out at water temperatures approaching 15°C. Heating costs in winter are likely to add over £20 per week to the cost of purification and is likely to make the cost of purification for this species prohibitive.

There are two different designs of purification plant approved by the MAFF and in use in Britain; open tank systems and high density tray units (Ayres, 1978). Open tank systems consist of one or more tanks of concrete, brick or wood filled with seawater in which oysters are placed on plastic netting trays. Water is pumped from the bottom of the tank(s) up to the sterilisation unit where it is irradiated with ultra-violet light, it is then allowed to fall approximately 60 cm to permit reaeration. From the aeration column seawater is carried in plastic pipes to the opposite end of the tank(s) where it is released through jets at the water surface. The system described by Ayres has a total capacity of approximately 9,000 litres which needs to be recirculated at least once per hour. Each half-tank can treat 5,000 oysters at a time.

The high density stack system was developed as a small, versatile unit suitable for small enterprises or inland use (artificial seawater can be used, Wood and Ayres, 1977). The units consist of a framework of wood or metal holding ten moulded plastic trays supported on runners in a stack (Figure 6.2). Water is pumped up from the sump tank through the ultra-violet steriliser onto the top tray. Overflows are so arranged that when the depth of seawater exceeds 7.5 cm water begins to pour into the next tray below. In this way the water percolates down through the stack to the sump purifying the oysters and being reaerated between trays.

Units of this type hold a total water volume of approximately 900 litres of which one-third is held in the trays. The total volume of water should be circulated at least once an hour corresponding to 30 water changes per tray per hour (Walne and Wood, 1973). A single ten stack unit will hold up to 2,000 mature oysters and additional units can be readily added as demand dictates.

Table 6.7 Capital and running costs for Oyster Purification Plants in 1979

7.a Concrete tank system

The capital cost of a tank purification unit exclusive of labour and maintenance costs is approximately £1,000 (P Ayres, pers comm). This may be broken down as follows:

Item	1979 Estimated Cost (£)
Base (6m x 3m)	150
Waterproofing ($40m^2$)	5 - 10
Concreting (6 - $7m^3$)	150
Water Pump*	150 - 200
Steriliser Unit	150
Power fittings	35
Piping and fittings	10 - 15
Drain	50
Steriliser and pump frame	40
Aeration box*	20 - 30
Trays	80 - 90
Overhead block and tackle*	120 - 130
Total	£960 - 1,050

*Estimated.

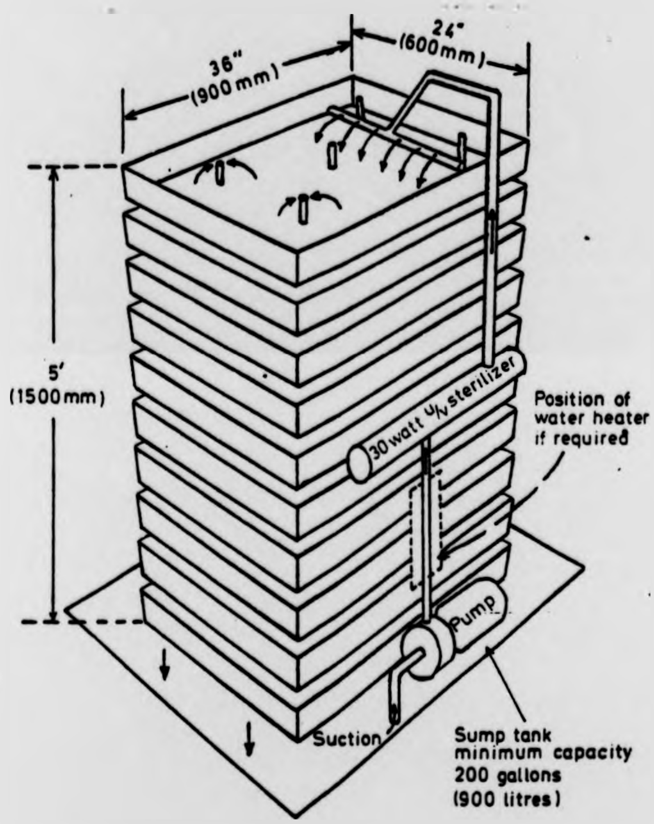
7.b. High density stacking system

The capital cost of the stack unit shown in Figure 6.2 is £300 (P Ayres, pers comm). This may be broken down as follows:

Item	1979 Estimated Cost (£)
Centrifugal water pump	60
Piping	10
Enclosed ultra-violet light steriliser unit	80
Sump tank and drain	50
Framework of 'Dexion'	45
Plastic holding trays	55
Total	£300

NOTE: Both designs to be written off over a ten year period although the useful life of the concrete tanks is likely to be greater.

Figure 6.2 A stacked oyster purification unit



Source: Ayres(1978)

2. Running costs for Oyster Purification Plants

The following table is an attempt to compare the running costs of both designs when used to purify from 100,000 - 1,000,000 mature oysters per annum. No attempt has been made to allocate directly labour or maintenance costs because of the difficulty in estimation.

Table 6.8

(a) Concrete tank system: holding capacity of Unit 10,000 oysters

No. oysters purified p.a.	Number in Thousands									
	100	200	300	400	500	600	700	800	900	1000
No. hours required	360	720	1080	1440	1800	2160	2520	2880	3240	3600
Running cost* (£/year)	10	20	30	40	65	75	85	95	105	115

(b) Stacking system: holding capacity of Unit 2,000 oysters

No. oysters purified p.a.	Number in Thousands									
	100	200	300	400	500	600	700	800	900	1000
No. hours required	1800	3600	5400	7200	9000	10800	12600	14400	16200	18000
No. stacks required	1	1	1	2	2	2	3	3	3	4
Running cost* (£/year)	49.5	106.5	163.5	220	285	350	414	486	558	630

*Includes the cost of electricity for pumping and sterilisation and of replacement ultra-violet lamps.

The above figures show clearly that the running costs for the stacking design are considerably higher than for the more extensive tank system. Nonetheless for the small-scale operator the low capital cost of the stacking unit more than compensates for the higher running costs. If the capital cost of each system, written off over a 10 year period is included in the running costs then below a figure of 150,000 oysters purified p.a. a stacked system is more economical to employ and above this figure a tank system should be favoured.

At present most individual operators are currently marketing up to approximately 1,000 mature oysters per week hence an investment in one stocking oyster purification unit will give ample capacity and be the most economic system for their needs.

6.9 INSURANCE

The function of insurance is to spread risks and in so doing share the financial losses any operator may suffer between all insurees. There is little doubt that at present aquaculture is still a high risk business. As more experience is gained it will be possible to reduce some of the risk and improve the quality of management decisions but it will never be possible to control fully or predict the environmental changes which affect the operation. It is the extremes of environmental conditions which are the most important from the point of view of insurance. Both the range of conditions which occur on the site and their probability of occurrence must be assessed to determine the type and magnitude of risk involved and hence the insurance cover required.

An analysis of this type of information has been carried out for trout farms based on data accumulated from 25 farms in Britain, France and Spain (Macfarlane and Varley, 1976). Results showed that the most common cause of large stock losses was water pollution and that system and husbandry failures accounted for most smaller losses. One conclusion reached was that the risk profile of an individual fish farm closely reflects the quality of management decision-making. Only when reliable estimates of the probabilities of major risks to a venture are available is it possible to make provision for insurance cover at a realistic cost.

In oyster culture we are dealing with an instance of almost pure uncertainty. Compared to trout farming there are fewer oyster growing enterprises, fewer years' experience and a wider range of techniques and equipment employed. Heavy oyster mortalities in the United Kingdom occurred in the severe winters of 1920, 1929, 1947, the east coast floods of 1953 and the winter of 1962/1963. Losses on the fisheries of the east coast of England reached 60–80% of the total stock in some of these years. There is some suggestion from such events for a periodicity of heavy oyster losses corresponding to between 10 - 15 years (Gardner, 1973). However, such data only refers to *O. edulis* fisheries and to date most ongrowing enterprises have concentrated on *C. gigas* at sites on the south coast of England or the west coast of Britain where conditions are less severe.

Insurance policies specifically designed for mollusc culture have been developed by some brokers specialising in aquacultural insurance. In view of the scarcity of data upon which to evaluate risks premiums have tended to be high and conditions of insurance more favourable towards the insurer. As with all forms of insurance a policy is no guarantee that all claims will be paid. The insurant has certain responsibilities to ensure that every reasonable step is taken to reduce the risk of losses. This may indirectly benefit the ongrower since the requirement for accurate stock records and careful planning at every stage will foster better management generally. It is important that both parties understand and agree upon the cover a policy offers. Underwriters may exclude losses due to cold weather and the inclusion of certain 'named perils' such as disease may considerably increase the cost of premiums. This is particularly relevant for the oyster grower to whom cold and disease may appear to be the greatest hazards to his operation.

The main types of insurance policy for oyster cultivation are those covering loss of stock and product liability. Generally the only viable stock insurance is full 'All Risk' cover since an ongrowing unit may be exposed to rapid and extensive losses of stock from many varied causes, eg pollution or storms. Coverage may be for all stock held but often oyster farmers merely insure to the value of their seed oyster costs thus enabling them to restock in the event of a significant mortality occurring.

In an attempt to keep premiums down to a level acceptable to the ongrower most insurance policies against stock loss include a franchise clause (Table 6.9). Losses of stock below the franchise value are non-claimable and claims for losses above this value are paid on the basis of the value of insured stock held at the time of the loss. The aim of such clauses is to distinguish between operating and abnormal losses and to relieve the underwriter of any exposure to small 'run of the mill' mortalities. A deductable clause may also be included by the insurer such that claims for losses above the franchise value are paid less the deductable percentage. Again the aim is to protect the underwriter from large claims. The effect of these clauses is most readily appreciated through an example:

An ongrower with an intertidal cultivation operation is insured to the sum of £50,000 with a stock loss policy of type 1(a) in Table 6.9.

At the time of the commencement of the loss the actual value of insured stock on the farm is £30,000. If the loss is below the franchise value of 35% no claim can be made. If the loss were 45% of the actual value of stock held then the claim would be as follows:

45% of £30,000		£ 13,500
less 15% deductable		£ (4,500)
	Claim	£ 9,000

The premium rates charged on stock insurance vary according to the method of cultivation and species (rates may be higher for *O. edulis* because of its longer life cycle). An average figure for premiums is 5 - 10% of the actual value insured (in the example above it would be £2,075 p.a.). The higher inherent risk involved with a new venture is reflected by the cost of premiums being set as 10 - 20% above those quoted for an established operation. The actual values of premiums, franchises and other clauses will vary depending on the unit under consideration. Normally an underwriter will require detailed information from the prospective insurant describing site conditions, culture techniques and previous experience before entering into a contract. Many ongrowers in view of the conditions imposed on such policies and the high cost of premiums choose not to insure their oysters or only to insure to the cost of replacement of seed oysters. For example in the case of an ongrower buying in 250,000 spat in 1979 the insurance premium for replacement cover is likely to be £100 - £200 which may be considered a worthwhile expenditure. In the subsequent economic analysis only stock insurance to the value of replacement seed oysters will be included.

Occurrences of food poisoning directly attributable to the consumption of oysters are rare yet insurance against product liability is regarded both by oyster fishermen and ongrowers as a necessary cost of their operation. Premiums depend on the site location and the degree of purification employed but are likely to be less than 0.1% of the value of the actual limit of insurance cover. Aquacultural Insurance Services Limited quote a premium range of £175 - £225 per annum for a policy which covers an annual turnover of 250,000 - 500,000 oysters.

Such an output range is more than adequate to cover virtually all ongrowers and fishermen. In the economic analysis the cost of product liability insurance will be taken as £200 p.a.

Table 6.9 Examples of aquacultural insurance policy premiums and conditions offered by brokers specialising in insurance cover for aquaculture

1. Aquacultural Insurance Service Limited

(a) Insurance against stock loss for mature *C. gigas* or *O. edulis*:

All risks of Mortality	% of Actual Value Insured		
	Premium	Franchise	Deductable
i. RAFT CULTURE			
Disease	5.35%	70%	20%
All other Perils	5.35%	35%	15%
ii. INTERTIDAL CULTURE			
All perils excluding disease	4.15%	35%	15%

Notes:

a. There would be no difference in the rates charged for mature *C. gigas* and *O. edulis*.
b. Underwriters will normally exclude losses caused by cold weather.
c. For a new venture or first time insurer a 20% increase in the rates given above would be expected.

(b) Public and product liability in respect of an oyster farm:

The premiums charged will depend on the individual merits of each case. For example the rates for an experienced oyster farmer may be lower. However, typical premiums for such a policy are:

(i) For a limit of £250,000 a premium of £175 could be expected.
(ii) Up to a limit of £500,000 a premium of approximately £225 could be paid by an insurer with an estimated annual turn-over of around £50,000.

2. Roberts, Morris Bray (Insurance Brokers) Limited

All risk insurance cover to the value of seed oysters held:

Type of Culture	% of Actual Value Insured		
	Premium		Franchise
	C. gigas	*O. edulis*	
Raft Culture	8%	10%	50%
Intertidal Culture	9%	11%	50%

Notes:

a. Indemnity period of three years.
b. All rates apply to first year and decrease by 2% in Year 2 and 1.5% in Year 3.
c. A new insurer would normally pay a 10% excess for the first three years or for three years after a claim.

6.10 DREDGING LICENCES AND FORESHORE RENT

Any individual may fish for oysters on a public fishery provided no local by-laws are contravened but all commercially exploited oyster fisheries are covered by one of three types of regulation:

Private ownership gives the present owner sole rights to make use of the seabed or to let, sell or transfer his rights as he pleases. Existing private ownership must date back to 1215AD (when such rights were last granted by the Crown) and although some oyster beds are private their importance is not significant when compared to other forms or rights to usage.

The Ministry of Agriculture, Fisheries and Food (MAFF) may grant a Regulating Order to a Local Authority, Sea Fisheries Committee or other body who is then vested with the power to administer the fishery and issue licences to the public to fish for oysters. The cost and conditions of issue of such licences vary between fisheries but generally they are inexpensive and normally restricted to residents of the area. Some examples are shown in Table 6.10

Table 6.10 The cost of oyster dredging licences on three Fisheries operated under a Regulation Order in 1979

Regulating Body	Site of Fishery	Cost of Licence (£/year)
Maldon District Council	River Blackwater, Essex	£1
British Transport Docks Board	Southampton Water	Free
Carrick District Council	River Fal, Cornwall	£40
Southern Sea Fisheries Committee	Poole Harbour	£10
Southern Sea Fisheries Committee	Solent	£250 (Effective Nov. 1980)

Ideally the cost of a licence should reflect the potential of an area for cultivation but this depends to a large extent upon the amount of effort the fisherman will expend on his holding and is not easily estimated a priori. In consequence there is no consistent basis for the realistic valuation of oyster dredging rights.

The third possible arrangement is a Several Order granted by the MAFF to an individual or company conferring the sole rights to the molluscan fishery in a defined area for a limited period. Such orders are issued subject to the condition that the applicant must satisfy the Ministry that they will bring benefit to their holding by cultivation (Davidson, 1976).

Sole rights to the use of the foreshore or seabed are essential for oyster culture. Applications to lease these areas must be made to the Crown Commissioners who administer Crown property. If a lease is approved, the District Valuer has the responsibility of determining a fair rent (no element of monopoly value is included). However, there is little previous experience of shellfish culture upon which to base a valuation and, in the past, rents have been fixed on an ad hoc basis, most growers being charged a nominal rent of £100 per annum.

To resolve this situation and to encourage the ongrower, the Crown Estate Commissioners in consultation with the National Farmers' Union have agreed a moratorium on rents for aquaculture effective for seven years from 1 January 1980. The agreement is that the Commissioners will accept a token rent of £20 per annum from each applicant, eg private individual or large company. At the end of this period it is considered that fish farming will have ceased to be experimental and the Crown will revert to their previous practice of asking the District Valuer to fix an appropriate rent.

Whilst this will bring an immediate financial benefit to the cultivator it does not solve the fundamental problem of how to assess a fair rent. It is to be hoped that the Commissioners together with the NFU can use the next few years to establish guidelines within which the District Valuators may operate and make provision for the right to appeal against a site valuation.

In the economic appraisal rents for the use of the foreshore will be costed as follows:

1979	£100	(Foreshore rents are expressed in *real* terms)
1980 - 1985	£ 20	
Post 1985	£100	

6.11 MISCELLANEOUS COSTS

6.11.1 Boats

All oyster ongrowing techniques utilise areas about or below Low Water Spring Tide Level. Access even at low tide will rarely exceed 2 - 3 hours per tidal cycle and hence the purchase of a suitable boat is essential.

For most forms of culture a 16 - 20 ft (4.9 - 6.1 m) clinker built or steel dory type vessel fitted with an inboard diesel or outboard engine of up to 10 hp would be adequate.

The cost of a suitable second-hand craft (one or two years old) in the trade press varies between £1,000 - £2,000 depending on age and specifications. If an allowance is included for some modification, eg simple lifting gear, then a price of £1,500 - £2,000 in 1979 for a boat with a working life of 5 - 10 years would appear reasonable.

In the case of enterprises where grant or loan assistance is offered aid may only be provided for the purchase of new equipment. A new vessel of the type described above should cost in the region of £2,500 at 1979 prices.

6.11.2 Electricity

Fish farms are classified as agricultural in most electricity generating board areas and power is supplied at the Farm Tariff Price..

Operators who work from their home may be charged the domestic tariff but the adoption of the Farm Tariff has the advantage that there is only one tariff whereas several domestic and industrial tariffs exist. Furthermore the Farm Tariff includes the 'farmhouse' if one is present on the site.

The cost of electricity employed is based on the tariffs operative from 1 April 1979 by the South of Scotland Electricity Board and the North of Scotland Hydro-electric Board. Together these two bodies employ most forms of generation and supply a diverse range of consumers and environments and should, therefore, accurately reflect the average cost of electricity.

Electricity charges at Farm Tariff Rate

Item	Cost (£)
Annual Fixed Charge	£26.00
Charge per KwHr consumer	£00.0275

The cost of electricity is included in the running costs of the oyster purification unit.

6.11.3 Packaging

In any industry as diverse as that associated with fish handling it is unlikely that a standard form of packaging will exist. The majority of fish supplied to the wet fish market are packed in non-returnable containers for distribution.

Plastic returnable boxes do have advantages with respect to hygiene, durability and ease of handling but their high cost (approximately £7.00 each) and the high loss rate within the industry has meant that their adoption has been only quite small. As a general rule of thumb the loss rate of plastic containers must be restricted to 25% or less before their longevity makes their use economically viable.

The hard external shell of bivalve molluscs gives ample protection to the shellfish during transportation and makes feasible the use of much lighter, inexpensive packaging than for finfish. Cardboard boxes are suitable for the transport of oysters if the cardboard is waxed or plastic liners used.

Prices quoted for cartons designed to hold 200 mature oysters (14 - 15 kilos) in 1979 averaged £0.75 per carton with a minimum order quantity given as 1,000 boxes. Using the above density an enterprise would need to market 200,000 mature oysters per annum to maintain a regular turnover of one order per year. The marketing of oysters would benefit from standardised, high quality packaging irrespective of the size or type of outlet. There will always be some cost associated with packaging and in the economic appraisal it will be included as the cost of non-returnable cardboard cartons at £3.75 per 1,000 mature oysters.

6.11.4 Additional costs

As with any farm enterprise expenditure on several minor but necessary items must be included. In the case of oyster culture this covers sieves for regrading spat, ropes, all-weather clothing etc. An expenditure of £250 is assumed, sieves are taken to have a 10 year life (cost £95 for a set of five stainless steel sieves), all other items are assumed to have a two-year life.

6.12 TAXATION

It is assumed that the oyster ongrower will run his business as a self-employed person and pay Income Tax accordingly. A complete record must be kept of all business transactions and the services of a professional accountant are normally employed to prepare financial statements. Any date may be adopted as the commencement of the financial year but in this study the Income Tax year is used. This also corresponds to the beginning of the main oyster growing season.

Shellfish and finfish culture for the production of food for human consumption is treated as agriculture for tax purposes and is eligible for the following tax relief:

(1) Where fish farming for human consumption is carried out by an individual as a sole trader or in partnership the profits may be averaged over two years, if appropriate, on the same rules as for farm profits (Section 28, Finance Act 1978).

(2) If a new venture run by an individual or partnership incurs losses in its first three years of trading, the individual or partner may set such losses against his income for the three preceeding years and reclaim income tax accordingly (Section 30, Finance Act 1978).

An oyster ongrower building up a commercial unit may be able to benefit from both types of relief. In the appraisal tax relief available under Section 30 has been included.

The personal Income Tax rates in force in the financial year 1979/80 have been used to estimate tax liability in each investment appraisal. The tax bands are as follows:

Slice of Taxable Income (£)	1-750	751-10,000	10,001-12,000	12,001-15,000
Tax Rate (%)	25	30	40	45

Personal allowances: Married person £1,815
Single person £1,165

Fish and shellfish for human consumption are covered by the zero-rating schedule of the Finance Act, 1972, and are exempt from Value Added Tax. This tax is levied on oyster growing trays and other equipment but it can be reclaimed if it is shown that they were used to produce zero-rated supplies. It has not been considered in this investigation.

Large enterprises registered as limited liability companies will be required to pay Corporation Tax. This has not been considered in the appraisal.

6.13 GENERAL OVERHEADS

This category of costs may vary greatly between different types of culture system and does not increase pro rata with the unit's productivity. In consequence administration, marketing and maintenance costs have, in the past, been allocated as a general figure expressed as a percentage of the annual operating costs of the venture.

Shepherd (1973) on the basis of a survey of several British fish farms estimated office and other administrative costs as 5 - 15% of the annual operating costs. In two later papers figures of 5 - 6% (Varley, ibid) and 7% (Hails, ibid) of the annual operating costs have been employed in appraisals of trout production units.

Similarly the cost of maintenance has been gauged with respect to running costs. Varley (ibid) used an estimate of 1 - 3% of total operating costs whereas Shepherd (ibid) costed maintenance at 20% of the annual depreciation allowance. Detailed investment appraisals of oyster culture units have been carried out as part of feasibility studies but the results, with a few exceptions, have been kept confidential. Figures from a 1973 feasibility study given to the author include clerical costs at £1,500 plus £250 for each additional million oyster spat over 2 million, maintenance at £1,500 plus £500 for each million over 2 million oysters and marketing costs as £500 in year 1 and thereafter as 10% of sales value.

Clearly general overheads depend on both the type and size of operation under consideration. The most consistently used approach is to allocate a figure as a percentage of the annual operating costs although it should be borne in mind that this also covers some fixed cost element. A figure for general overheads equivalent to 10% of the annual operating costs will be adopted. Maintenance is costed separately as 20% of the annual depreciation allowance. Overheads constitute primarily administration costs with an element of marketing cost: This latter representing ordering and advertising expenses only since delivery and packaging have been costed separately.

6.14 THE COST OF CAPITAL

By investing loaned or private resources in an aquaculture venture the operator will normally forego the opportunity to invest capital in alternative projects. The cost associated with such investment decisions is known as the opportunity cost of capital. In the case of borrowed capital it is equivalent to the interest charged and for private investment it is equal to the interest which could be accrued from alternative investments.

The rate of interest charged on the 'open' market will reflect how the market views the risks associated with fish farming. Since aquaculture is a high risk business it is likely that only government funded agencies will offer loans at interest rates favourable to the operator.

The White Fish Authority and Highlands and Islands Development Board interest rates for the industry are fixed at the level prevailing at the time of loan approval. White Fish Authority assistance is currently only available to the fish catching and processing sectors but nonetheless provides a yardstick against which fish farm loan rates of interest may be fixed.

White Fish Authority interest rates on Loans
June - July, 1979

Fishing vessels	13 - 14%	
Processing plants	14 - 15%	('Fishing News' 6.7.79)

In general the rate of interest charged on loan assistance to the industry is set at approximately base rate. Throughout 1979 the average monthly figure for the Bank of England Minimum Lending Rate was 14% (Central Statistical Office).

If the operator uses his own capital the opportunity cost will be the return possible from risk-free investments such as government bonds. The operator's target rate of return, however, will depend upon how he evaluates the risks associated with the project. It has been suggested that fish farmers should not aim for a return of less than 30% on total capital (McAnuff, 1980). It is not clear whether this is intended to be a market or real rate of return. In cases where a venture is financed solely by the operator it may not be possible to give a definite cost of capital. In such instances either several possible rates of return may be tested or the internal rate of return (IRR) for the project calculated. In this study the latter approach is adopted.

6.15 GRANT AND LOAN ASSISTANCE

In certain circumstances financial aid in the form of grants or loans is available to the shellfish farmer but the availability and levels of this assistance falls considerably short of that available to agriculture.

Fish farmers are specifically excluded from the Farm Capital Grant Scheme. The only grants provided under Agricultural Grant Schemes are those furnished under the Farm and Horticultural Development Schemes but the levels of FHDS aid to fish farming are lower than those for land farming. This type of grant is available only to cultivators who have an income per labour unit of less than the national average income of workers in non-agricultural occupations and who can submit a development plan showing that in six years their income will reach this level. Situations where such help would be available are clearly limited, for example an individual ongrower might be eligible for a grant to develop an oyster nursery but a large established unit would not.

Oyster fishermen may qualify for aid under the Sea Fish Industry Act 1970 or the Sea Fisheries (Shellfish) Act 1967 and 1973. The former Act established a grant and loan scheme administered by the White Fish Authority which provides finance towards the purchase of vessels or the establishment of processing plants. Oyster ongrowing operations fall outside this scheme as current regulations stand. The Sea Fisheries (Shellfish) Act provides grants or loans for cleaning and reinstating (including restocking) any shellfish beds which have been affected by disease or pests.

In Northern Ireland, the Highlands of Scotland and other Special Development Areas fish farmers are often eligible for assistance under special schemes. Under the Assistance to Fish Farming Scheme (Northern Ireland) 1973, the Department of Agriculture (NI) operates a grant aid scheme which provides up to 30% of the approved expenditure of setting up an oyster cultivating enterprise. Grants may be given for buildings, equipment or the preparation of shellfish beds. Loans for fish farming are also available; up to 45% of the approved expenditure where the purchase is grant aided and up to 75% where no grant aid is given. Repayments on these loans are half-yearly (1 March and 1 September), over a period not exceeding 15 years.

The Highlands and Islands Development Board in Scotland has the power to make aid available to oyster cultivation projects. Special Grants may be offered by the Board, the amount of which is calculated with reference to what is felt necessary to make the project succeed subject to an overall limit of 20% of the total cost for sizeable projects. Overall Board assistance must not normally exceed 60% of the total cost of the project (including working capital as well as fixed investments).

Loans for the purchase of new plant, equipment, buildings or provision of working capital are available at interest rates fixed at the level prevailing at the time of Board approval, normally at approximately base rate (circa 14% in 1979). Loan periods are usually for 10 years (up to 20 years for buildings) and within the pay-back period the Board may award an interest-free period for up to two years and defer repayment for the same period. This would make the loan repayable in eight equal instalments commencing on the third anniversary of the advance. By this time an oyster ongrower should have been able to market mature *C. gigas* for one year and will be receiving some return on his investment.

The situation with regard to the provision of grants or loans is generally unfavourable for the fish farmer. Much of the relevant legislation was conceived prior to the advent of commercial shellfish culture and is clearly not designed for aquaculture. This has further penalised the ongrower since it is not possible to gain eligibility to European Economic Community assistance until the enterprise is in receipt of aid from its home government.

Aquaculture is a high risk business and financial institutions are generally unwilling to provide finance for such ventures. Under such circumstances central government may be the only source of assistance and as such has a crucial role to play in the development and ultimately the commercial viability of the industry. However, a small industry such as fish farming which develops with too great a dependance upon government aid is very prone to bankruptcy if government policy towards the industry changes (Needham, 1979). The majority of oyster cultivators will not have access to any form of government assistance and the author considers that it would be inappropriate to include such aid in a general appraisal of commercial oyster production. The calculated rates of return for oyster culture reflect the true commercial viability of such ventures.

6.16 RATES

The subject of the rateable values of fish farm sites has been an area of controversy for a number of years. The General Rate Act 1967, Section 26, gives all agricultural buildings a zero-rateable value. The Act goes on to define livestock as:

> 'Any mammal or bird kept for the production of food or wool or for the purpose of its use in the farming of land'.

The specific omission of fish or shellfish in this definition is the basis for the decision not to consider fish farming as qualifying for derating. Fish farmers argue that producers of fish or shellfish for human consumption are producing food and should, therefore, be classified as agriculture. The definition of livestock as currently used by the Inland Revenue is both too restrictive and is not consistent with definitions applied in other legislation, eg The Town and Country Planning Act, 1971.

Footnote: As from 1 April 1981 fish farm sites have been derated.

The rateable value of industrial premises is based on the value of land and buildings plus fixed plant and equipment not within a building. In contrast to most types of industrial premises the bulk of the investment on a fish farm is not contained within a building but is in the form of holding facilities for the stock. Thus the fish farmer or nursery operator in particular will be penalised.

In an attempt to remove this anomoly fish farmers are recommended by the NFU to appeal against their rating valuations through the Land Tribunal and Local Valuation Courts. Cases which have reached the courts to date in England and Wales have been successful but the cost of such legal action is an additional financial strain on the individual operator. With this in mind perhaps the most significant recent case is the attempt by Shearwater Fish Farming (a subsidiary or British Oxygen Company) to have its Cumbrian site derated. This company has adequate financial resources to cover the legal costs of its action or any appeals which may arise as a result. Its ultimate success will go far towards securing derating of all aquaculture sites.

In the model oyster ongrowing sites will be assumed to have zero-rateable value. This stance is justifiable for two reasons. Oyster cultivation uses primarily the foreshore and makes only minimal use of land, eg a store or small purification plant. The rateable values of such premises, if applicable, should in the case of oyster culture be very low. The campaign to derate fish farms is well orchestrated and should ultimately be successful.

.17 PLANNING AND LICENCES

The use of any land for the purposes of agriculture or buildings used in connection with agricultural land does not constitute development requiring planning permission. The only exceptions are where the development does not meet the requirements with regard to area of development, height of buildings, distance from and redevelopment of access to trunk or classified roads. The definition of livestock as used in the Town and Country Planning Act 1971 includes:

> 'Any creature kept for the production of food, wool, skins or fur, or for the purpose of its use in the farming of land'.

Fish farming, therefore, is included and any land based facilities used in connection with the farming of oysters should be exempt from planning permission.

Licences in order to conform with other legislation may, however, be required. Any aquaculture enterprise may need a licence from the appropriate Ministry or Department of Agriculture. In Northern Ireland a Fish Culture Licence issued under Section 11 of the Fisheries Act (NI) 1966 is required in order to farm oysters. The establishment of a marine farm requires a licence from the Department of Industry under the Coastal Protection Act 1949 which is rarely granted if any party objects (Pullin, 1977). Effluent from the farm must comply with the Control of Pollution Act 1974, and the Dumping at Sea Act 1974 may have implications for oyster growers. This latter Act makes it an offence to dump (or load for the purpose of dumping) any material in the sea from a vehicle, ship, aircraft, hovercraft or other marine structure without a licence from the relevant licencing Authority (Norton, 1976). Although intended to control the dumping of industrial wastes and sewage sludges it is possible that an oyster ongrower discarding dead oysters from a raft could be prosecuted under the Act.

There is no financial cost associated with the ongrowers' acquisition of any of the above licences but every appropriate permit should be procured if he is to avoid the possibility of infringements which might lead to prosecution.

6.18 PROTECTION AGAINST THEFT OR DAMAGE

On private oyster beds and those administered by a 'Several' Order the owner or leasee has legal title to all produce of the fishery. However, the maximum fine for poaching or damaging the shellfishery in any way is based on the original Shellfisheries Acts of 1868, 1869 and 1875 and stands at £20. This is long overdue for review when one considers that during the 1978/79 season Grade 1 Native Flat Oysters were wholesaling at Billingsgate Market at £3.36 per dozen.

Similarly the ongrower using the foreshore may have less legal protection for his oysters than he believes, particularly if his site is regarded as encroaching upon public rights of access. Some degree of protection is given by the Criminal Damages Act 1971 (Section 5(2)) but if an individual believes (whether justified or not) that by his action he was defending a public right of access to the foreshore or sea, or a right to fish or dig bait then a magistrate's court might find for the defendant in a damages case.

In the case of theft the onus would be on the fish farmer to prove that an individual knew he was acting dishonestly when he stole shellfish. In the Theft Act 1968, Section 2, the appropriation of property of another with intent to keep it is not dishonest if the individual does it in the belief that he has a legal right to deprive the other of it, or if he believes that the owner cannot be discovered. By claiming to have been unaware that for example oysters laid on an intertidal bed were private property or subject to private rights then it is conceivable that a prosecution for theft might fail.

These statutes were intended to protect the public right of access and in some cases date in various forms back to the Magna Carta. In virtually all instances they entered the statute books before oyster cultivation in trays became a commercial reality and, therefore, take no account of it. There is a need for a revision of the relevant Acts to ensure adequate legal protection for the ongrowers' stock and equipment such as is taken for granted by land-based industries.

Chapter 7

THE ECONOMICS OF OYSTER CULTIVATION

7.1 INTRODUCTION

The technical problems associated with aquaculture have largely been solved over the last decade. This progress has yet to be matched by the acceptance and application of techniques to test the commercial viability of the systems developed. In cases where feasibility studies have been conducted the economic information generated is often either superficial or considered commercially valuable and not disclosed.

Some recent studies have attempted to carry out investment appraisals on the cost of certain types of oyster culture. In his thesis, Askew uses simple Discounted Cash Flow (DCF) techniques to establish the commercial viability of intertidal oyster cultivation in trays. A breakdown of the capital and operating costs for growing *C. gigas* intertidally at Menai Straits has been attempted by Spencer (1978). A cost analysis of the use of wooden trays, imported Japanese Lantern nets and NWP trays for ongrowing *C. gigas* to a size of 70g has been carried out (Briggs, 1978).

Each of these appraisals has important limitations. The latter study suggests that the cost of cultivating oysters in suspended lantern nets and on trestle supported trays is similar. However, only the costs of the actual holding units and frames is considered. Comparisons of this type should consider the full capital and operating costs of each system.

Spencer (ibid) adopted a more realistic approach and included the costs of labour as well as capital expenditures. This study only considers the culture of small oysters up to a maximum size of 4 grammes. The duration of the appraisal is too short to provide reliable information on the long term profitability of such a venture.

A more comprehensive analysis has been attempted by Askew. He considers projects which extend over a period of up to three years and by employing a DCF method takes into consideration the time value of money. Under the best conditions tested his results showed that at 1974 price an operation to produce 1,000,000 *C. gigas* of 80 grammes from 0.5 gramme spat yielded a project Net Present Value (NPV) of £16,800 using a discount rate of 15%. The economics of such an operation were shown to be very sensitive to changes in parameters. Increasing the ongrowing period for *C. gigas* from one to two years under the same conditions reduced the project NPV to £-3,600.

This was one of the first aquaculture studies to use sensitivity analysis on an economic appraisal but in the author's opinion oversimplifies the analysis and is limited in its scope. The scale of operation considered was a unit to produce 1,000,000 mature oysters per annum with a project life of up to three years. It seems unlikely that a new entrant in to an untried business such as shellfish cultivation would start with such an ambitious production programme over such a short time span. Consideration of the cultivation of *O. edulis* is restricted to an appraisal of a four month cycle to grow 10 gramme seed oysters from 0.5 gramme spat. No consideration of the commercial viability of growing this species to maturity is included yet this is the oyster which commands the premium market price. This omission may in part be explained by the unusually rapid growth rate for this species predicted by his model. Given the model's poor fit to field growth observations any attempt at investment appraisal based on its results would not be justified.

In view of the limited work to date the author considers that there is still a need for a detailed appraisal of the economics of oyster cultivation based on long term projects and applicable to both species grown in the United Kingdom.

In any business where there is an element of uncertainty it is prudent to carry out an economic appraisal of the opportunity before any investment of capital is made. The need for such an evaluation is vital in circumstances such as oyster cultivation, where there is little prior experience and the inherent risks to the enterprise are numerous. Each site has a unique set of characteristics which are outside the control of the operator, eg food availability, weather conditions. It is vital that each operation is independantly appraised and that the analysis is based upon complete and realistic estimates of all outlays and incomes.

Fish farming has been increasingly under the scrutiny of generalised appraisals in recent years. The adoption of such a broad approach though has often failed to communicate to the practical cultivator the value of the techniques employed.

The criteria on which this study is based have been established from discussion with individuals directly involved in the industry and scientific and technical data collected from the literature and commercial concerns. Cultivators all stressed the need to use low cost equipment and in the analysis emphasis is placed on the utilisation of techniques and equipment which have gained commercial acceptance. In keeping with the aim of realism the scale of operation has been limited to a one-man enterprise where cost control should be most readily achieved.

The derived computer growth and mortality model forms the basis upon which the analysis will be constructed. The author considers the model as both a realistic reflection of oyster growth in the sea and sufficiently flexible to account for changes in the growing environment.

The objective of this study is to prepare, from a basic set of criteria, a series of investment appraisals and graphs from which an evaluation of commercial viability can be made. It is hoped that the appraisals followed by sensitivity analysis will give a good insight into the economics of cultivating both species under a range of conditions. The analysis will illustrate how management techniques may be used to assess projects. In so doing the study may contribute to the wider acceptance and use of such methods in the aquaculture field. The ultimate judgement as to whether aquaculture is an attractive investment is a subjective one which only the individual investor can make. The intention of this study is to provide information pertinent to this decision-making process.

7.2 METHOD

Information obtained from the costings performed in Chapter six and from the results of the derived computer model (Chapter five) has been used to construct investment appraisals. The approach adopted has been to calculate a standard investment appraisal for each independent proposal (Anthony and Reece, 1975). In each case the Discounted Cash Flow (DCF) method has been employed to consider both the amount and timing of net incremented cash flows. A payback period has also been calculated for each project. The time increment employed throughout is one year and it is assumed that the project year runs from April to April. This has been adopted to comply with the Taxation year and is particularly appropriate for oysters as April is the first month when the environment is suitable for the planting out of spat in the sea. A worked example of how revenue and a comprehensive set of costs are derived and employed in the investment appraisals is given in Appendix II.

7.2.1 Methods of investment appraisal

One of the simplest methods of choosing between different projects is the payback period. This is a non-discounting technique which is widely used in industry. The payback period method consists of selecting those projects whose profits are big enough to repay the amount invested within a chosen number of years. Projects can be ranked in terms of the number of years which they take to recoup the initial outlay. This method has been used to eliminate oyster projects with very long payback periods but has several shortcomings if used on its own. The technique is myopic ignoring projects with high yields but long payback periods and is biased in favour of short payback periods. As such it can lead to the selection of high risk projects which offer a rapid return.

A more objective approach is to use discounting techniques. The DCF method recognises the time value of money; that is that cash received in one time period is worth more than the same sum received in a later time period. This must be true since money received now can be invested and earn interest until such time as it is required. Discounting is the mechanism which gives a common denominator in time. It is a prerequisite of applying any DCF technique that the timing and amount of all cash inflows and outflows consequent on each of the alternative projects must be determined. The two most widely used DCF methods are Net Present Value (NPV) and Internal Rate of Return (IRR).

The NPV is the surplus of the discounted value of profits less the initial investment. More precisely it is calculated as the present value of the project's net cash flow discounted at the company's cost of capital to the time of the initial capital outlay minus the initial capital outlay:

$$NPV = \sum_{t=o}^{t=n} \frac{A_t}{(1+r)^t} - C_o \qquad \text{..........} \qquad \text{Eq. 7.1}$$

C_o = initial capital outlay

A = Net cash flow (Revenue - costs)

r = rate of discount

t = time (years)

This method has the advantage of providing a simple measure, in monetary terms, of a project's worth but has the disadvantage of necessitating the discount rate to be predetermined.

An alternative method is to calculate the Internal Rate of Return. The IRR finds by trial and error the rate of return which equates the discounted value of the profit stream with capital outlay. This requires the same assessment of net cash flows as the NPV method but obviates the need to decide upon a discount rate. The solution is the discount rate which would equate the NPV to zero. Put more formally, one solves equation 7.2 for the discount rate (r).

$$\text{IRR given by} \sum_{t=o}^{t=n} \frac{A_t}{(1+r)^t} = 0 \qquad \text{..........} \qquad \text{Eq. 7.2}$$

The important distinction is that with the NPV method a given discount rate is used to find the present value surplus, while with the IRR method one finds the rate of discount which makes the NPV = O. The NPV is generally accepted by economists as being theoretically unassailable if one wishes to maximise profits. The IRR formula is a polynominal and can give rise to multiple roots. Fortunately most of these roots can be ignored as they are negative or imaginary (Hawkins and Pearce, 1971). In projects where large capital outlays occur in years after year O causing a loss to be made during that year an extended form of the IRR equation must be used. The basis of this method is that negative cash flows are discounted back at the firm's cost of capital until they are offset by positive cash flows. If these conditions are borne in mind the IRR method is as valid for decision making as NPV. The IRR has the advantage of giving some idea of the 'leeway for risk' offered by a project and many businessmen prefer to work with a rate of return figure rather than with the absolute value of NPV.

The problems of trying to establish a suitable cost of capital for aquaculture have been outlined earlier (Section 6.14). The discount rate adopted should reflect both the degree of risk the project involves and the opportunity cost of employing capital in this rather than any other investment. If the ongrower could achieve a higher return on his capital from a low risk investment such as government bonds he would be unwise to invest in aquaculture, ceteris paribus.

For the NPV method the investor's cost of capital should be employed as the discount rate if profit maximisation is the main objective of the investment. There is no general agreement, however, on how the cost of capital is calculated. If finance is derived from several sources then the cost of capital must reflect the costs used by each of these sources. In established enterprises historical rates of return give a guide to likely future rates and may be used in establishing the cost of capital. In new industries such as shellfish culture this information does not exist. The.presence of high risks may warrant the use of high discount rates in investment appraisals but their effect is difficult to quantify.

If the appropriate rate of interest is unknown then the Internal Rate of Return method can be used. In this study only the pay-back period and IRR methods have been employed. All cash flows are taken at constant prices and are independent of any consideration of inflation. The effects of risks on the project have been reduced by the inclusion of insurance. It is assumed that the procurement of insurance cover eliminates a substantial element of risk by spreading the risk over all insurees. Allowance for named loss risks need no longer be accounted for in rate of return projections if insurance is included. A discussion of the acceptable rate of return for oyster culture is left to the end of this chapter.

It is normal practice in commerce to establish a target or hurdle rate of return above which projects are acceptable to the investor. Market rates of return reflect the current level of inflation whereas real rates are net of any inflationary effect. The prospective real return must be sufficiently high to compensate for the risk involved. Aquaculture is a high risk business and this is reflected in the use of a hugh hurdle rate of return in Chapter Seven.

7.2.2 Investment appraisal computer programme

To facilitate the handling of the data in the investment appraisals and to minimise computational errors a search was undertaken to find a suitable computer programme to perform the investment appraisals. The criteria used to select the programme were:

(1) The programme must use the IRR method.
(2) The facility to perform sensitivity analysis must be present.
(3) Output from the programme should be the minimum conducive with the scope of the analysis.
(4) The programme had to be readily accessible.

The programme selected is the Fortran package called INVANL (Honeywell, 1973). The programme analyses return-on-investment by computing a payback period and a discounted rate of return for a series of cash flows. The programme follows a standardised procedure for calculating rate of return. It is designed particularly for determining profitability and economic justification for investment.

There are two parts to the programme: a cash flow analysis and a return on investment analysis. The objective of the cash flow analysis is to compute the yearly cash flow resulting from the investment and to determine its payback period. The aim of the return on investment analysis is to compute the average annual rate of return from the investment based on a discounted cash flow method.

In this study the computed Internal Rates of Return, payback periods and undiscounted cumulative cashflow graphs will be utilised in the interpretation of the investment appraisal results. An example of an investment appraisal using the INVANL programme is included in Appendix II.

7.3 RESULTS

The analysis centres on an investigation of the economics of establishing and operating a venture to produce 100,000 mature oysters per annum. There are two species (*Ostrea edulis* and *Crassostrea cigas*) and two sites (Emsworth and Menai) considered and the four possible combinations form the base from which the study is developed. Subsequent investment appraisals look more closely at the effects of changing specific factors, eg mortality rate on the commercial viability of each of these four 'key analyses'.

All the cumulative cash flows presented in the analysis exhibit a similar graphical pattern. At this point it may be useful to outline the interaction between costs and revenue which gives rise to this type of graph.

All appraisals start with a negative sum in year 0 which represents the initial capital expenditure. The value of this negative cash flow increases each subsequent year until the point where the stock of oyster spat planted out in year 1 are marketed. As successive crops of oysters are marketed the accummulated negative cash flow will diminish provided the yield and selling price are sufficient to generate enough income to offset the operating and a proportion of the accummulated costs.

The payback period is the point at which the cumulative net cash flow plot intersects the abcissa. To the right of this point any accummulated cash flow will provide a positive rate of return on the investment (IRR %). In all the appraisals the peak net cash flow is achieved in the penultimate year. This is the final year in which oysters are marketed. The decrease in cumulative cash flow in the final year represents the lagged payment of taxation on the previous year's gross profit.

In each case the appraisals cover ten years marketing of mature oysters. In addition there is the lead time when oyster spat are growing to maturity and a final year when deferred tax is payable. This extends to a maximum total appraisal time of sixteen years for *O. edulis* produced at the Menai site. The adoption of this time scale is sufficient to show the long term returns a project offers yet remains manageable. A period of 10 - 15 years also coincides with the expected working life of the capital equipment employed. Truncating the project life in this way foregoes returns in later years and is one method of allowing for uncertainty.

7.3.1 Oyster spat planting-out scheme

It is essential that the production in future years is planned with a reasonable degree of accuracy. If it is assumed that growth and mortality rates are similar each year it is possible to forecast the requirement of oyster spat to achieve the target production level.

The pattern of revenue flows will depend on species, the ongrowing environment, and the months when spat are planted out in the sea. The first two factors are considered in the analysis but the latter has been established a priori. The timing of the purchase and laying out of oyster spat is important since:

(1) The pattern of growth and survival is partly determined by the temperature regime employed.

(2) It may be unrealistic to have all mature oysters ready for marketing in the same month.

(3) The planting out months which permit a steady marketing of mature oysters differ between species.

(4) The traditional season for marketing *O. edulis* is restricted to the period September to April (when there is an 'r' in the month).

In order to simulate the operation of a commercial venture we need to establish which months yield the optimum production schedule, how many months spat purchases should be spread over and how many spat should be laid out in each month to achieve the desired production level.

The derived multiple regression model has been used to establish planting out schemes for both species at each site and for two initial spat sizes. Two further assumptions have been made in preparing this plan. It is assumed that the growth rate of each batch of oysters represents the average rate and is exhibited by all oysters. The medium mortality rate as described in Equation 5.13 has been used to estimate survival in all appraisals. Where the effect of varying mortality rate is discussed (Section 7.3.3) the spat requirement for appraisals using the low and high mortality equations (Equations 5.12 and 5.14) have been calculated separately.

The predicted spat requirements at a production of 100,000 oysters per annum for each of the 'key appraisals' is shown in Table 7.1. At higher levels of production the spat requirement increases in direct proportion to the increase in unit size and follows the same planting out scheme.

The results show the number of spat to be laid out and the months of planting out under each set of conditions. Also included in Table 7.1 is information regarding the ongrowing period predicted by the model and the size and month when the oysters are harvested.

At the Menai site both species of oyster are planted out over a three month period whereas at the Emsworth site a four month period is employed. This reflects the shorter growing season under the poorer temperature regime at Menai. The first planting out of *C. gigas* is made in April as this species will grow at a lower temperature than *O. edulis*. By commencing the ongrowing period in the Spring both species are able to make maximum use of the favourable summer climate. If the larger spat size is used then either the ongrowing period is reduced or larger oysters are marketed.

Batches of *C. gigas* are marketed in successive months to give a total annual production of 100,000 oysters. The month of harvesting *O. edulis* is given throughout as September. This species does not grow during the winter and no significant increase in size will occur after September. The size at this date will be the size marketed throughout the oyster season. Oysters of this size may not grow over the winter but they will be subject to mort-

Table 7.1 Spat planting out scheme to produce 100,000 oyster per annum

(a) Emsworth Site

Species	0.1 gramme spat					0.5 gramme spat				
	Initial month	No. spat planted out	Size (g) harvested	Month harvested	No. months grown	Initial month	No. spat planted out	Size (g) harvested	Month harvested	No. months growth
C. gigas	April	33750	71.0	August	17	April	33750	86.5	August	17
	May	33750	81.0	Sept.	17	May	33750	80.0	August	16
	June	33750	80.5	October	17	June	33750	82.0	Sept.	16
	July	33750	77.0	Nov.	17	July	33750	82.0	October	15
O. edulis	May	37500	80.5	Sept.	41	May	37500	82.5	Sept.	41
	June	37500	80.5	Sept.	40	June	37500	82.0	Sept.	40
	July	37500	72.0	Sept.	27	July	37500	80.0	Sept.	39
	August	37500	88.0	Sept.	38	August	37500	70.0	Sept.	38

(b) Menai Strait

Species	0.1 gramme spat					0.5 gramme spat				
	Initial month	No. spat planted out	Size (g) harvested	Month harvested	No. months grown	Initial month	No. spat planted out	Size (g) harvested	Month harvested	No. months grown
C. gigas	April	45000	70.0	October	19	April	45000	75.0	Sept.	18
	May	45000	73.5	Dec.	20	May	45000	80.0	October	18
	June	45000	72.0	Feb.	21	June	45000	75.0	Nov.	18
O. edulis	May	50000	74.0	Sept.	65	May	50000	77.0	Sept.	65
	June	50000	73.5	Sept.	64	June	50000	76.5	Sept.	64
	July	50000	76.0	Sept.	63	July	50000	76.0	Sept.	63

ality. Allowance has been made for this in calculating the spat requirement to achieve the desired production level.

7.3.2 The effect of spat size

Systems for growing oyster spat in hatcheries or land-based nurseries are expensive to operate. It makes economic sense, therefore, to transfer spat to relatively inexpensive tray systems in the sea at the earliest feasible date.

The smallest size of spat which can be successfully cultivated in trays is 0.1 g (Parsons, 1974). In the analysis investment appraisals were performed using this size and 0.5 gramme spat. The latter size represents the largest spat size supplied by most commercial hatcheries. The objective of these appraisals is to determine whether the shorter growing period and higher survival expected from the use of large spat outweighs the cost disadvantage of buying in at this size. The results for both species grown at each site are summarised in Table 7.2 and the cumulative net cash flow plots are shown in Figures 7.1 and 7.2.

C. gigas grown at Emsworth

The results for this analysis show that the use of 0.5 gramme spat yields a slightly higher rate of return. This difference of 1% in the predicted IRR is associated with a one month shorter pay-back period when 0.5 spat are utilised. The net cash flow plots for the two spat sizes (Figure 7.1) are very similar and even though the larger spat size yields a consistently higher cumulative net cash flow the difference could not be called significant.

C. gigas grown at Menai

At this site the different spat sizes appear to have a significant effect on the projects viability. The larger size gives an IRR of 10.8% and a payback period of 6 years 3 months (Table 7.2). By comparison the use of 0.1 gramme spat would appear to be uneconomical.

Figure 7.1 The effect on project cash flow of using two spat sizes in the culture of *Crassostrea gigas* at the Emsworth site

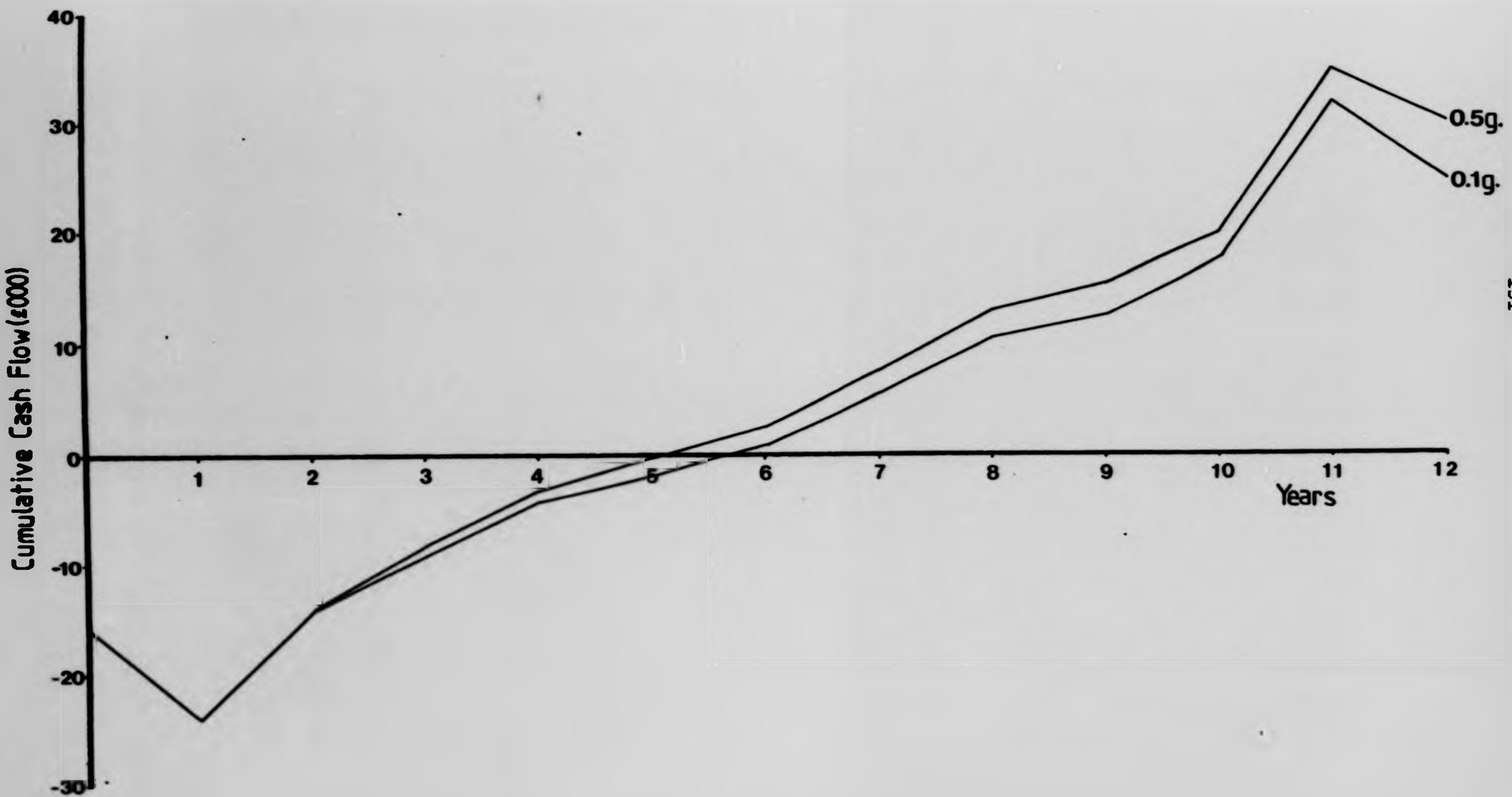


Figure 7.2 <u>The effect on project cash flow of using two spat sizes in the culture of *Crassostrea gigas* at the Menai site</u>

Table 7.2 Summary of investment appraisal results for proposals using different sizes of Spat

Species	Site	Spat size (Grammes)	IRR (%)	Payback period	Cumulative net cash flow (£)	% oyster surviving to 70+ grammes
C. gigas	Emsworth	0.1g	15.1	5yr 2mth	248200	77.9
		0.5g	16.2	5yr 1mth	29829	83.6
	Menai	0.1g	-	-	(397)	74.5
		0.5g	10.8	6yr 2mth	16924	81.5
O. edulis	Emsworth	0.1g	23.5	5yr 1mth	99355	71.9
		0.5g	19.7	5yr 4mth	83178	71.4
	Menai	0.1g	9.3	9yr 4mth	42788	54.4
		0.5g	9.1	9yr 5mth	43876	57.4

£( ) indicates a negative sum.

The undiscounted cumulative cash flow does not intersect the abcissa until the eleventh year and the payment of tax in year 12 results in a cumulative net cash flow of £-397 over the project life (Figure 7.2).

This result is particularly interesting as it illustrates the complex way in which the monthly initial size and temperature regime interact in the multiple regression model used to determine growth. In this example 0.1 gramme spat are laid out in batches over the period April - June and require an average of 20 months to reach a marketable size. The small spat size and slow growth rate at this site ensure that these oysters only achieve a predicted average size of 64.6g at the beginning of their second winter in the sea (ie October). By comparison spat laid out at 0.5g have reached a predicted average weight of 78.9g by the same date and will be marketable. Furthermore, spreading the planting out of spat over several months affects the grade of marketed oyster. Batches laid out in months with high seawater temperatures grow faster and tend to achieve a larger market size than oysters laid out in colder months. The difference in selling price between the two largest grades of each species is £4 per hundred. Temperature regimes which produce premium grade oysters will generate much more income than regimes which produce purely the lower grade. This affect is shown in Table 7.3 where the size distribution of marketed oysters in each of the key appraisals is shown. These results are based on the use of 0.1g spat, a similar breakdown would not occur with 0.5g spat.

Table 7.3

Site	*C. gigas*		*O. edulis*	
	grade		grade	
	A(75g+)	B(50-75g)	1(80g+)	2(70-80g)
Emsworth	50.2%	49.8%	72.4%	27.6%
Menai	0%	100%	35.1%	64.9%

For *C. gigas* grown at Menai only the smaller grade B size oysters are predicted by the model. In conclusion it may be said that the negative return calculated for this proposal is caused by the low site temperatures and small spat size resulting in a long ongrowing period. The large difference in IRR between the two spat sizes is explained by the 0.5g spat maturing to purely grade A oysters and the 0.1g spat being marketed as grade B oysters only. In the sea, however, growth rates may not be as clear cut as the computer model predicts.

O. edulis grown at Emsworth

The performance of oysters grown from 0.1g spat exceeds that of 0.5g spat derived stock (Figure 7.3). This result reflects the scarcity of growth data for *O. edulis* under certain conditions.

In the model the combination of the high instantaneous growth rate (G30) of 0.1g spat and high seawater temperatures result in very rapid early growth for oysters planted out in July. These conditions are the limit for which data was available. Under those specific circumstances the growth rate and consequently revenue generated by a batch of 0.1g spat exceeds that of a batch of 0.5g spat.

If growth data for *O. edulis* under these extreme conditions becomes available then the model could be updated to rectify this anomoly. At present this effect has been minimised by the use of a four month spat planting out plan such that only 25% of the spat are subject to this high initial growth rate.

The investment appraisal results show that the two spat sizes yield similar rates of return (Table 7.2). The cumulative net cash flows plotted in Figure 7.3 are very similar, even though the project life is relatively long (14 years). This would suggest that spat size may not be a major factor in determining the commercial viability for this species.

Figure 7.3 The effect on project cash flow of using two spat sizes in the culture of *Ostrea edulis* at the Emsworth site

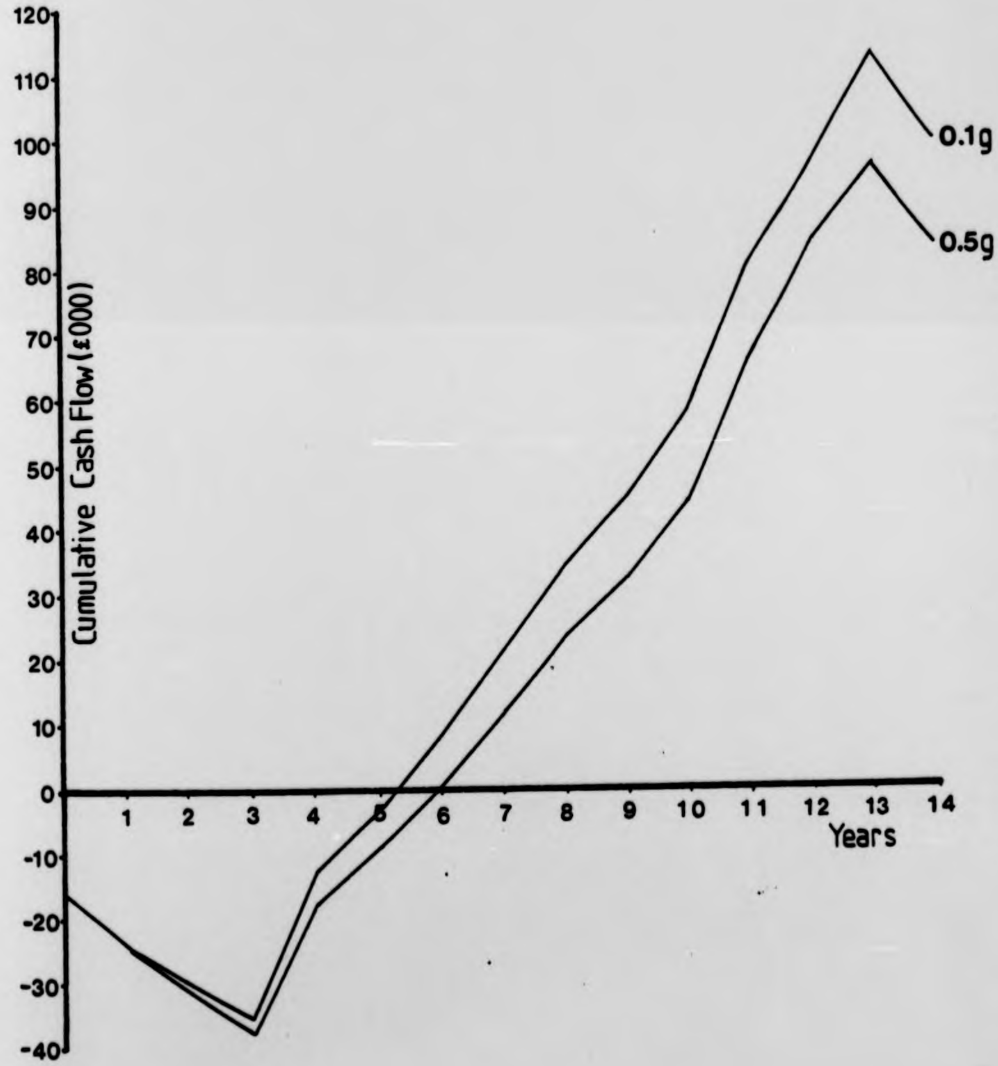
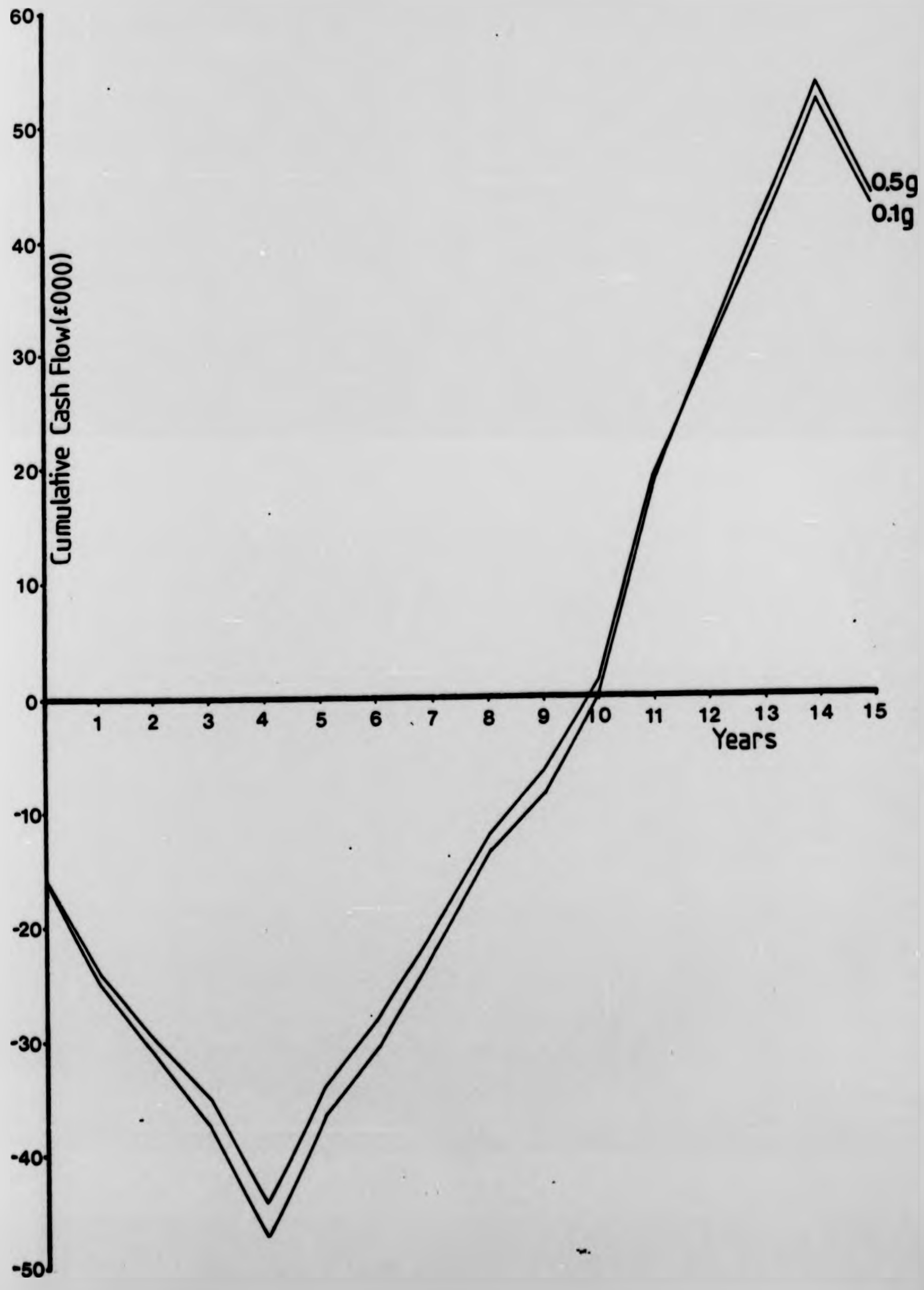


Figure 7.4 The effect on project cash flow of using two spat sizes in the culture of *Ostrea edulis* at the Menai site



O. edulis at Menai

The lower site temperatures in this appraisal do not create any difficulties concerning the growth of very small spat. The larger spat size results in the larger return on investment but the difference is negligible (Table 7.2). Figure 7.4 shows that over a 15 year project life no significant deviation between the two graphs. This lends credence to the suggestion that the slower growth rate of this species nullifies any economic advantage given by the use of large spat in a project of this duration.

A general point which is evident from these appraisals is that the effect of spat size is more marked where there is a shorter growth period in the sea.

The high selling price of *O. edulis* overall yields a much higher return on investment than similar proposals to cultivate *C. gigas*. This is in spite of its much slower growth rate.

It has been suggested that predicted survival rates for *O. edulis* may be over-optimistic. The use of only the high mortality rate may be more appropriate for the modelling of *O. edulis* in the sea.

Mixed culture of *O. edulis* and *C. gigas*

The different returns on investment and growth rates of the two species present the cultivator with a dilemma as the more lucrative species is the slower growing. At some point in the project life the investor might try to spread his risks or obtain a more rapid turnover of capital by cultivating a mixture of the two species. To provide an estimate of the likely returns on such an investment the returns from projects to produce 50,000 of each species per year were calculated. The results are summarised in Table 7.4 and not unexpectedly fall between the returns obtained from projects to grow one species only.

The results indicate that mixed oyster culture yields intermediate rates of return. In the long term an investor may best protect his investment and minimise risk by spreading his operation to cultivate both species of oyster or indeed other molluscan shellfish. Subsequent appraisals will, however, be restricted to consideration of the cultivation of either species only, as these appraisals should indicate the range of investment opportunities open to the investor.

Table 7.4 Summary of investment appraisal results for mixed culture of *O. edulis* and *C. gigas*

Site	Spat Size	IRR (%)	Payback	Cumulative Net Cash Flow (£)
Emsworth	0.1g	20.0	5yr 1mth	54,407
Menai	0.1g	8.6	9yr 1mth	28,889
Emsworth	0.5g	18.4	5yr 3mth	51,736
Menai	0.5g	10.3	8yr 3mth	34,151

It is not possible to establish conclusively that either spat size is the more economical to use other than for *C. gigas* at Menai. Appraisals covering the range for which most growth data is available show that the effect of spat size on return on investment is small. To simplify the analysis, in all subsequent investment appraisals only one size of spat will be considered. In the industry, at present, cultivators buy in mainly the smaller spat sizes. Hence all further investment appraisals will assume that spat is bought in at a uniform weight of 0.1 grammes and grown in the sea to a market size.

.3.3 The Effect of Mortality Rate

The derivation of a computer model to calculate the monthly survival of oysters growing intertidally has been discussed earlier (Chapter Five). It is sufficient to recall here that the model permits the use of any of three mortality rates; Low, Medium or High. In these appraisals the effect of employing each rate on the viability of the operation will be tested. Elsewhere in this chapter where the effect of varying other factors is determined the medium mortality rate is used.

The effect of predicted mortality may be studied in two ways in this analysis:

(i) Varying the initial spat requirement to maintain an annual production of 100,000 oysters, or

(ii) Maintain the original spat requirement and investigate the change in the production of marketable oysters.

From the computer model estimated of the spat requirement to maintain an output of 100,000 oysters per annum have been calculated and are shown in Table 7.5.

In the cases where the high mortality rate is used there will also be a need to increase the tray requirement and labour input. At Menai depending on the mortality rate employed the cost of spat alone may vary from £1,119 to £3,139 per annum. Such differences demonstrate the value of pilot scale growth trials to identify areas where favourable survival rates may be achieved.

From the point of view of the ongrower it is impossible to estimate a prior what the level of mortality is likely to be. Furthermore it would be wasteful from a financial point of view to always stock in anticipation of sustaining a high mortality rate.

By comparison if the spat requirement was not changed the difference in the final cumulative net cash flow between using the low and high mortality rate in the above example is £92,237. Clearly this latter approach has far greater consequences and is a more realistic method to adopt. In the sensitivity analyses performed this approach has been adopted.

Table 7.5 Spat requirements to produce 100,000 oysters per annum

Species	Mortality Rate	Site			
		Emsworth		Menai	
		Spat requirement	Total p.a.	Spat requirement	Total p.a.
C. gigas	Low	27,500 (April-July)	110,000	38,200 (April-June)	111,600
	High	42,700 (April-July)	170,800	62,600 (April-June)	187,800
O. edulis	Low	27,800 (May-August)	111,200	40,300 (May-July)	120,900
	High	51,600 (May-August)	206,400	113,000 (May-July)	339,000

C. gigas Results

The results summarised in Table 7.6 and plotted in Figures 7.5 and 7.6 show that changes in the level of mortality employed significantly affect the project rate of return. The use of the high mortality rate decreases the percentage survival by 24 - 29% and causes a fall in the cumulative net cash flow of approximately £1,200 for each percentage drop in survival. The result when the low mortality rate is employed exhibits a similar change in the cash flow for each percentage change in survival.

The relatively fast growth rate of *C. gigas* explains why the number of oysters surviving to a marketable size does not vary a great deal between sites. At both temperature regimes used *C. gigas* requires less than two years in the sea to grow from spat to market size. Under such conditions cumulative growth and mortality patterns have little opportunity to diverge.

O. edulis Results

In contrast with *C. gigas* the growth of *O. edulis* is much slower and any differences in the seawater temperatures of the two sites will have much longer to act. A divergence in the survival rates of oysters occurs and results in markedly different cash flows over the project life.

The effect on the cumulative net cash flow that these changes in mortality have is evident on the graphs (Figures 7.5 - 7.8). In value terms the effects are much more dramatic in the case of *O. edulis* (Figures 7.7 and 7.8). This may be attributed to the high selling price this species commands compared to *C. gigas*. As revenue is the product of yield and Selling Price, for a comparable decrease in yield, the fall in revenue is greater for the more expensive species.

The overall effects of these changes are now apparent. In the case of the faster growing species *C. gigas* the effect of changes in the rate of mortality upon survival are similar under both

Figure 7.5 **The effect of varying the mortality rate in projects to cultivate *Crassostrea gigas* at Emsworth**

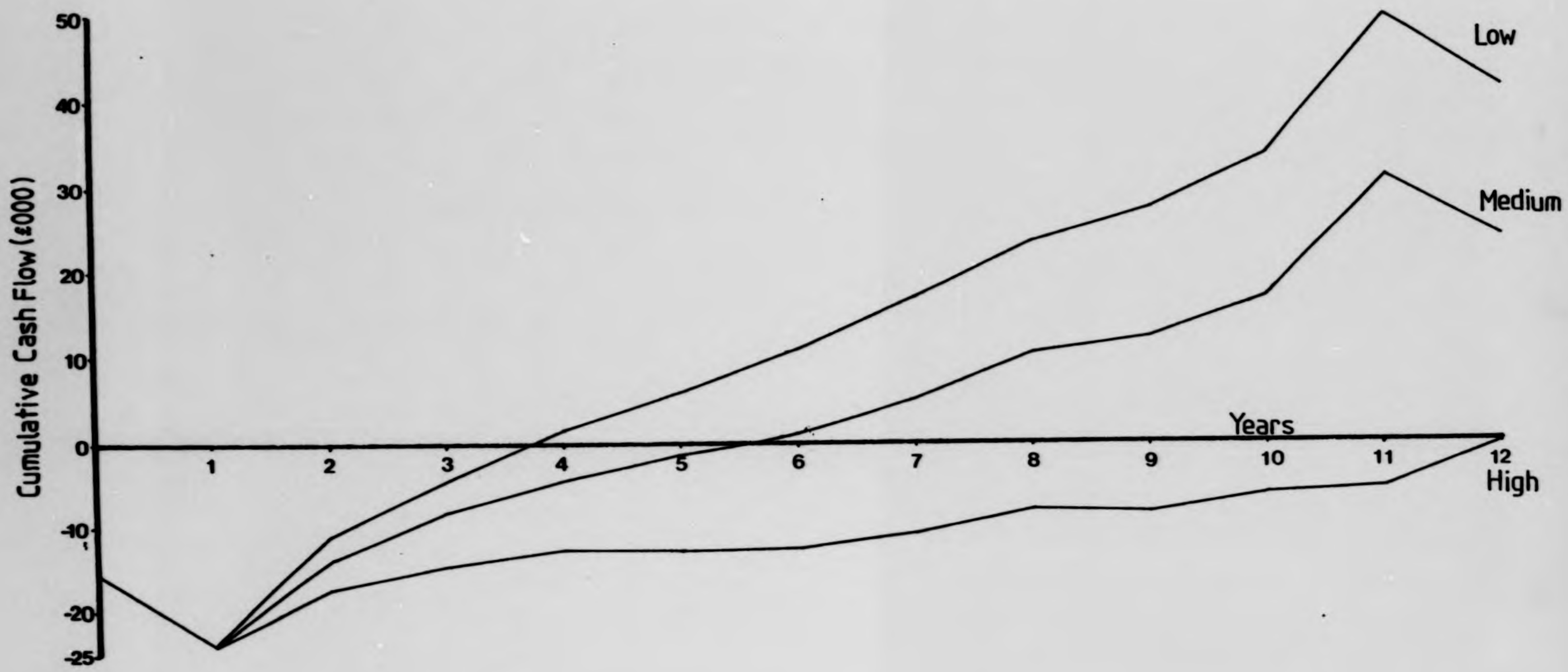


Figure 7.6 **The effect of varying the mortality rate in projects to cultivate *Crassostrea gigas* at Menai**

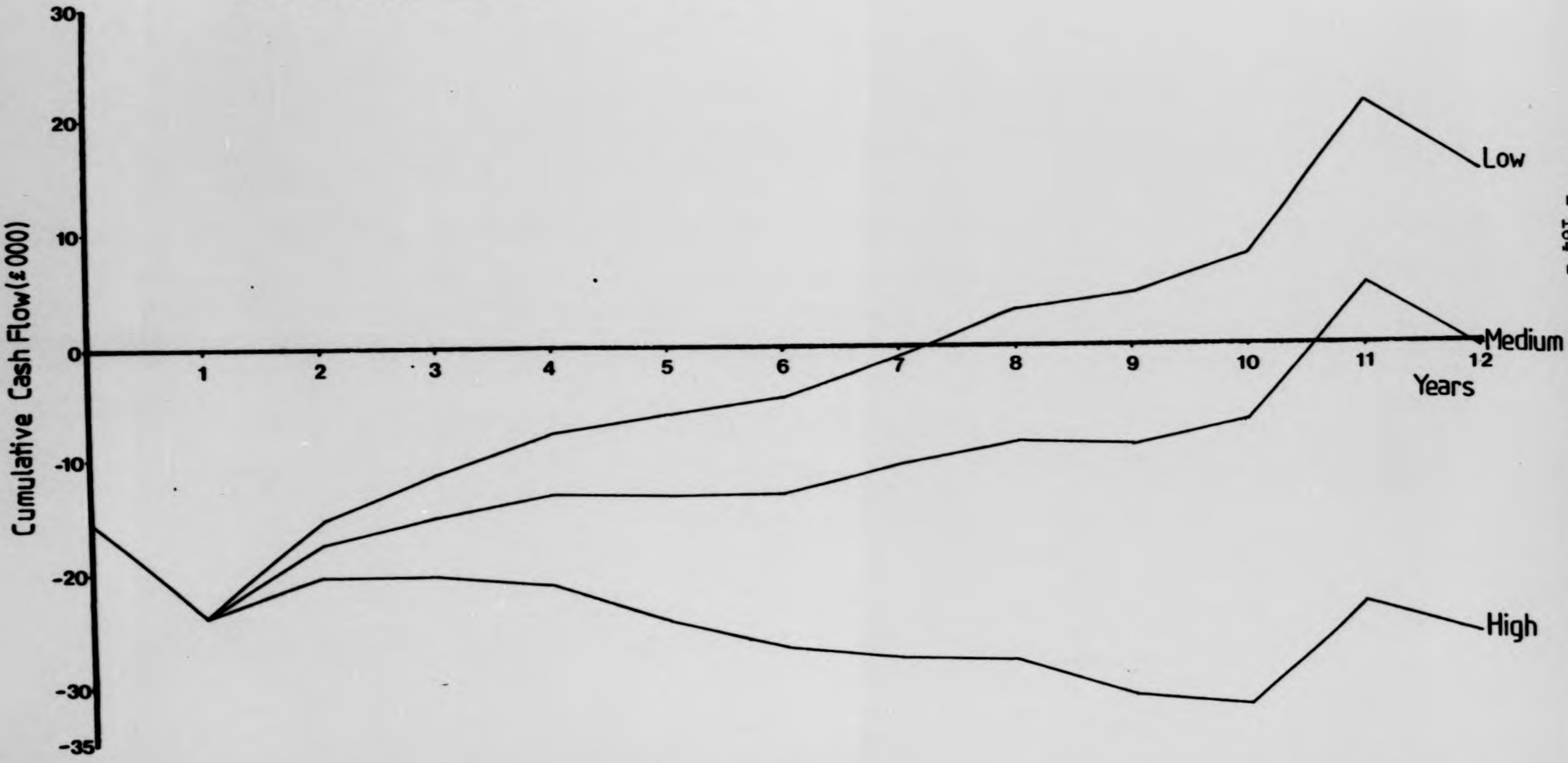


Figure 7.7 The effect of varying the mortality rate in projects to cultivate *Ostrea edulis* at Emsworth

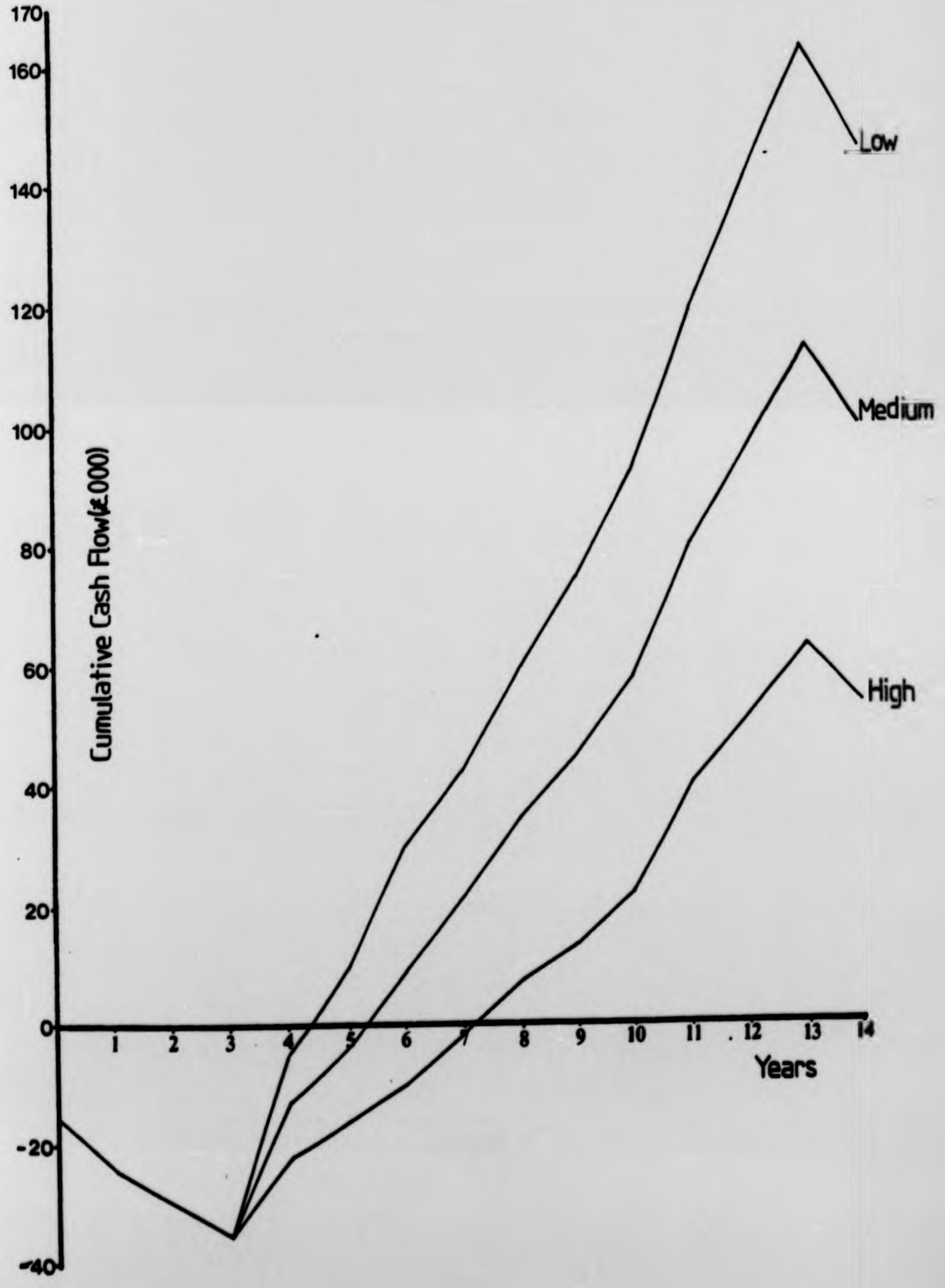


Figure 7.8 The effect of varying the mortality rate in projects to cultivate *Ostrea edulis* at Menai

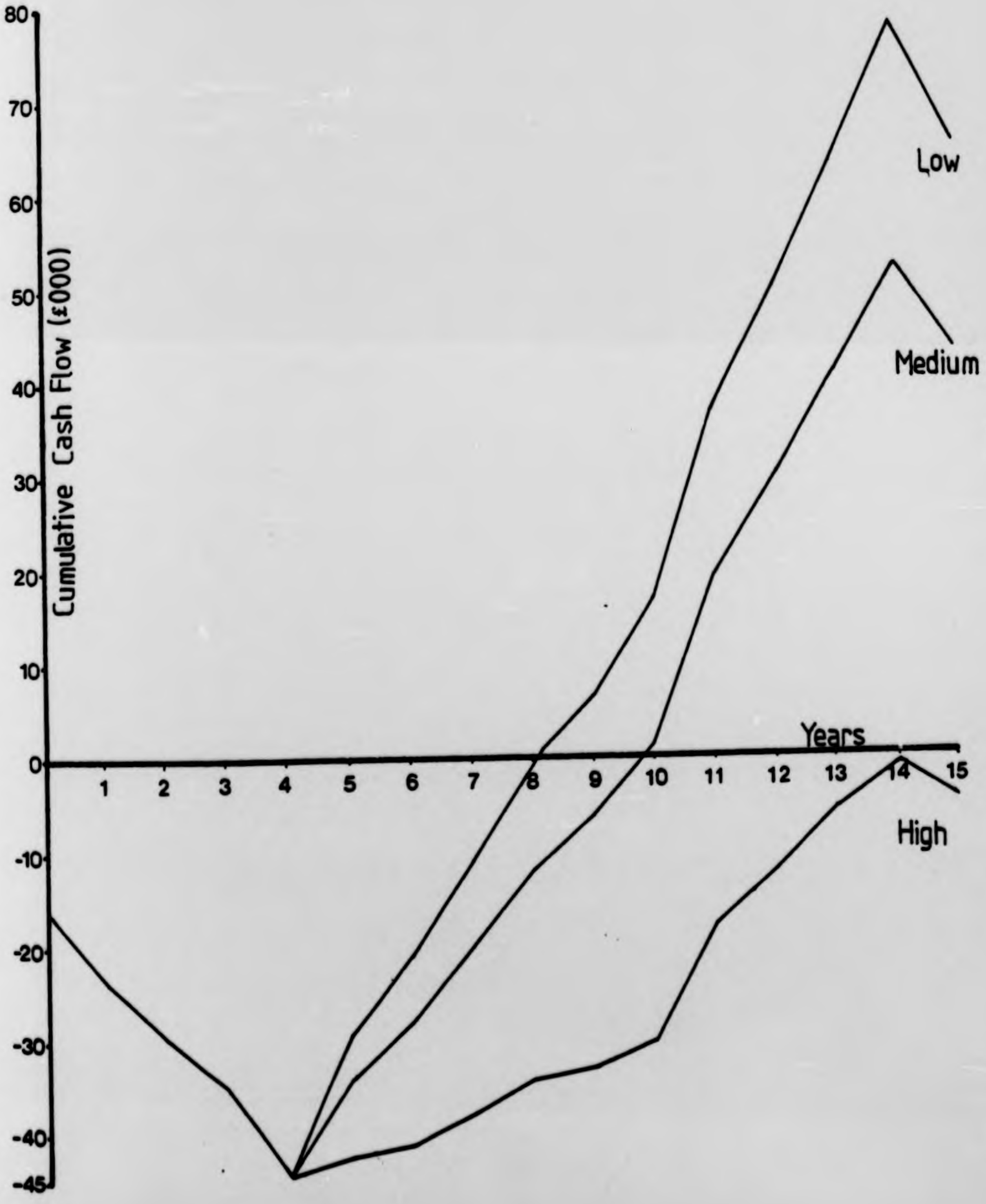


Table 7.6 **The Effect of varying the Mortality Rate on the Commercial Viability of a unit to produce 100,000 marketable oysters per annum grown from 0.1g spat**

SPECIES	SITE	MORTALITY RATE: Low				Medium				High			
		IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	% Survival	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	% Survival	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	% Survival
C. gigas	Emsworth	23.53	3yr 4mth	41,907	91	15.13	5yr 2mth	24,820	77.9	-	-	(35)	58.6
	Menai	9.7	7yr 1mth	15,015	89.6	-	-	(397)	74.5	-	-	(25,589)	53.3
O. edulis	Emsworth	30.19	4yr 2mth	145,738	90.0	23.5	5yr 1mth	99,355	71.9	14.35	7yr 1mth	53,501	51.6
	Menai	13.23	8yr 1mth	65,873	82.8	9.33	9yr 4mth	42,788	54.4	-	-	(4,462)	29.6

temperature regimes. The slower growth rate of *O. edulis* give ample time for differences in the survival rate to manifest their impact. The comparatively high price of this species, however, serves as a buffer to insulate the return of investment from all but the sharpest decline in the survival of oysters to market size.

The survival of oysters is governed by a host of factors which are mainly outwith the control of the cultivator. Mortalities may occur at any stage of the growing period in the sea and the operator must decide whether the expected returns outweigh the risk of a heavy mortality.

The high and low mortality rates employed in this analysis are based on the 50% confidence limits of field observations and may be considered as extreme examples. It is unlikely that either extreme will prevail continuously throughout the full project life. Therefore, these appraisals may be considered as boundaries of commercial viability within which an enterprise of this size might be expected to operate under normal conditions.

Finally it must be noted that this analysis takes no account of incidences of mass mortalities. Such events have been discussed earlier (Section 5.2.2). They occur too infrequently to predict with any degree of accuracy. If and when they happen their effects are so widespread and long-lasting as to decimate the entire industry let alone one small unit. The magnitude of their effect would make any investment appraisal under such conditions impractical and superfluous.

.3.4 The Effect of Temperature

The derived computer model is based on a multiple regression relating size and seawater temperature to growth. To date the model has been used to investigate two different temperature regimes: Emsworth and Menai. By changing the seawater temperatures used in the analysis a sensitivity analysis may be performed to determine oyster growth and survival and hence the project's commercial viability in each case.

There are an infinite number of possible temperature variations but in this study changes will be restricted to a maximum range of $\pm$ 1.5°C about the 'key appraisal' temperature regimes. This range is sufficient to cover the highest average monthly seawater temperatures likely to be recorded in the British Isles. Even in sheltered inlets seawater temperatures are unlikely to exceed 20°C and maintain conditions suitable for oyster growth. Adoption of this temperature range is also sufficient to give an overlap between the monthly seawater temperatures used at each site.

The effect of temperature on Survival

It can be seen from the results summary (Table 7.7) that in each instance a change in the temperature regime affects the number of oysters surviving to market size. A temperature increase leads to an increase in survival and vice versa. The scale of this effect depends on the magnitude of the temperature change, the species and the site. This is an indirect effect since temperature in the model directly affects growth and predicted mortality is a function of the size achieved at the start of each month. It is the slower growing species, *O. edulis* which exhibits this temperature effect most markedly.

Throughout the sensitivity analysis performed on the effect of seawater temperature a consistent pattern emerges. An increase in the average seawater temperatures leads to an increase in the cumulative net cash flow and brings forward the point when the payback of the original investment is achieved. Reductions in temperature have the opposite effect and may reduce the profitability of the proposal to such an extent that a positive IRR is no longer achieved. The indirect effect of temperature on survival is negligible compared to the effect of oyster size on mortality.

C. gigas grown at Emsworth

Temperature changes in the range of $\pm$ 1.0°C about this temperature regime were investigated (Figure 7.9). A reduction in temperature reduced the cash flow of the project when compared

Table 7.7 __The Effect of varying the Temperature Regime upon the Return on Investment__

CHANGE IN TEMPERATURE REGIME	EMSWORTH								MENAI							
	C. gigas				*O. edulis*				*C. gigas*				*O. edulis*			
	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	% Survival	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	% Survival	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	% Survival	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	% Survival
+ 1.5°C													29.4	3yr 3mth	88,167	72.3
+ 1.0°C	20.0	4yr 1mth	34,479	79.8					18.6	4yr 2mth	31,702	76.9	18.0	6yr 2mth	70,265	66.4
+ 0.5°C	19.4	4yr 1mth	33,188	76.8					7.0	8yr 1mth	10,403	76.0	15.7	6yr 4mth	59,185	61.2
NO CHANGE KEY APPRAISAL'	15.1	5yr 2mth	24,820	77.9	23.5	5yr 1mth	99,355	71.9			(397)	94.5	9.3	9yr 4mth	42,788	54.4
- 0.5°C	10.3	7yr 1mth	16,064	76.7	17.6	6yr 2mth	68,629	65.6	4.3	9yr 3mth	6,205	72.4	5.0	1yr 3mth	26,312	47.8
- 1.0°C			(477)	74.9	9.0	10yr 1mth	42,867	69.1			(4,308)	71.8				
- 1.5°C					6.4	10yr 10mth	35,595	52.2								

to the 'key appraisal'. The size of the fall was determined by the magnitude of the temperature change. A 0.5°C temperature decrease reduced the cumulative net cash flow by £8,747 but a further 0.5°C reduction resulted in a much larger decrease of £16,541. The poorer growth and survival achieved at lower temperatures accounts for the reduced rate of return. In the latter case this effect is compounded by a reduction in the number of large oysters predicted by the model.

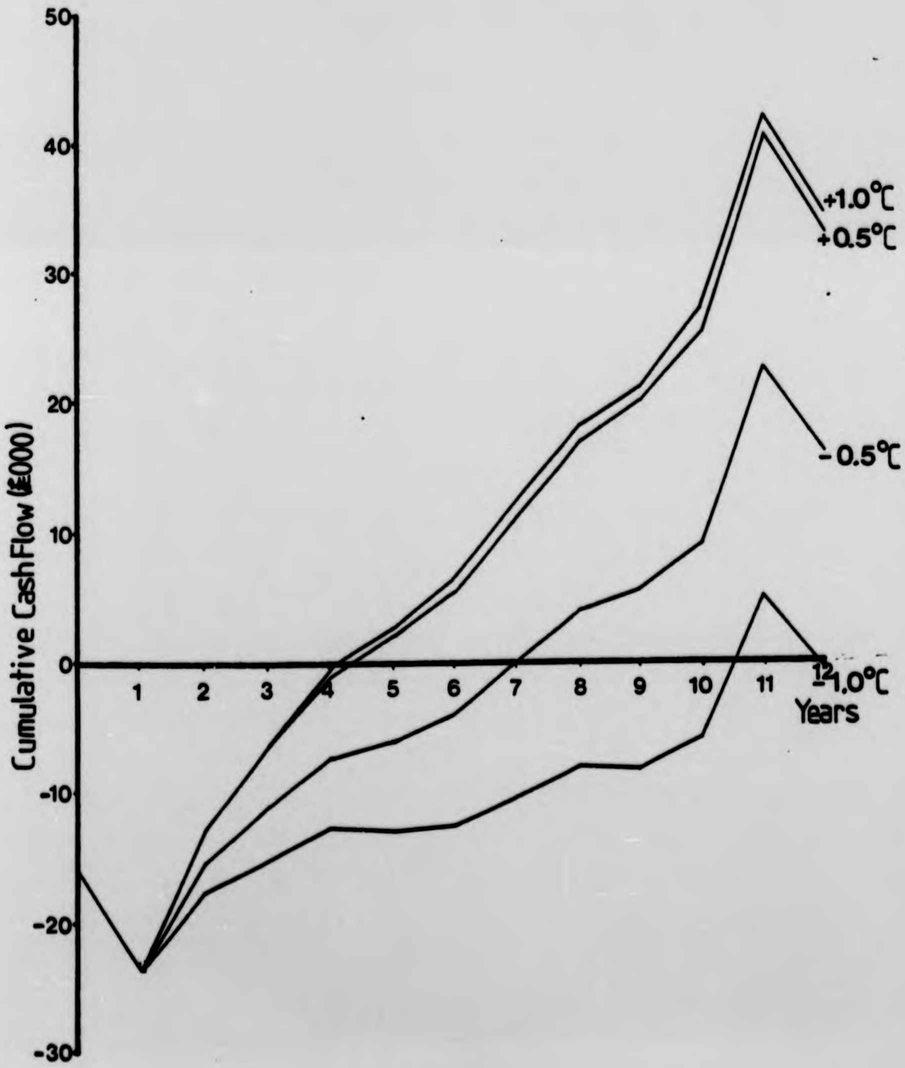
	Distribution of Marketable Oyster Sizes	
Temp. change	Grade A	Grade B
No change	50.2%	49.8%
- 0.5°C	50.2%	49.8%
- 1.0°C	25.1%	74.9%

At the lowest tested temperature regime only 25% of the oysters produced attain the larger grade and hence market price. In all cases the oysters reach market size within two years.

The temperature increases show an increased rate of return over the 'key appraisal' (Table 7.7). The difference in cumulative net cash flow resulting from these two examples is, however, only £1,291. Both these sets of conditions produce solely Grade A oysters of an average size of 80 grammes. The + 1.0°C example produces this crop in an average of 15.5 months compared to 16 months for the + 0.5°C example.

This relatively small difference in rate of return may be explained in terms of the relationship between seawater temperature and instantaneous growth rate (G30) derived earlier (Figure 5.5). This relationship is asymptotic and over the high temperature range considered here the gradient is slight. Thus the model predicts similar growth and survival patterns at these two temperature regimes and consequently similar rates of return are realised. At lower temperatures the effect of seawater temperature on growth rate is proportionally greater and hence the difference in investment appraisal results were marked.

Figure 7.9 The effect of varying the temperature regime for the culture of *Crassostrea gigas* at Emsworth



C. gigas grown at Menai

Again increasing the temperature increases the IRR of the project but a much greater divergence between the plotted cumulative net cash flows is evident (Figure 7.10). This is explained partly by the proportionally greater effect lower temperatures have on the seawater temperature against growth rate (G30) relationship. Moreover there is also a difference in the mix of mature oysters predicted by the model in each case, i.e.

Temp. change	Distribution of Marketable Oyster Sizes	
	Grade A	Grade B
No change	0%	100%
+ 0.5°C	33.5%	66.5%
+ 1.0°C	100%	0%

The production of only premium grade oysters boost considerably the revenue accrued in the + 1.0°C example.

From Table 7.7 it may be seen that the IRR of the - 0.5°C example exceeds that of the 'key appraisal' which realises an undiscounted loss of £397 over the project life. Once again the mix of mature oysters produced explains the result. A reduction of 0.5°C in the temperature regime increases the calculated average ongrowing period from 20 months to 23 months. This is more than offset by the production of 33.9% Grade A oysters whereas none were predicted for the 'key appraisal'. This difference can be traced to the batch of oyster spat planted out in June, the last of the three months employed. In the 'key appraisal' spat laid out in June attain 72.1g 21 months later in February. At the same point spat under the - 0.5°C temperature regime are only 59.9 grammes. These oysters require a further three months to exceed the target size of 70 grammes and achieve a weight of 77 grammes when marketed. This places one-third of the annual production in the higher price bracket. The timings of the cash flows are not affected since all oysters are marketed within two years of planting out.

The final appraisal shown in Figure 7.10 uses a temperature regime 1.0°C lower than the 'key appraisal'. This results in a negative cumulative cash flow of £4,308 over the life of the

C. gigas grown at Menai

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+ 0.5°C	33.5%	66.5%
+ 1.0°C	100%	0%

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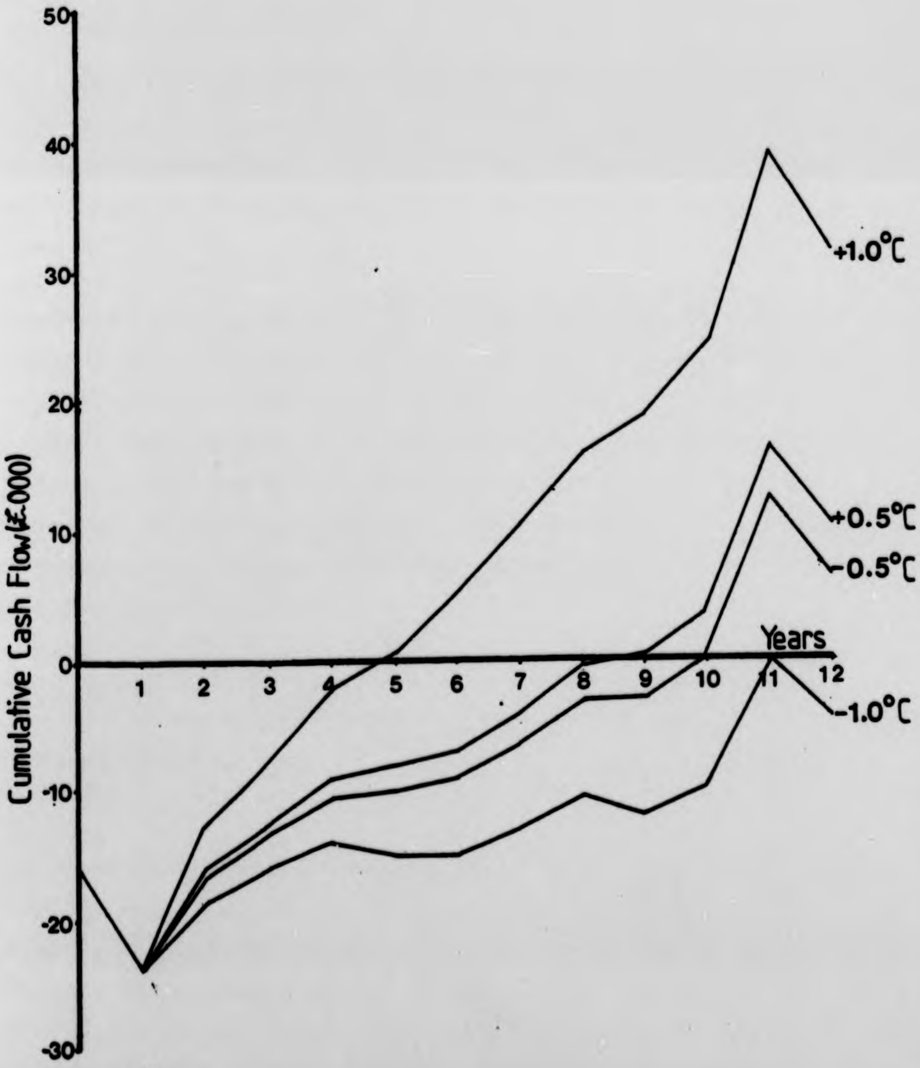
Figure 7.10 The effect of varying the temperature regime for the culture of *Crassostrea gigas* at Menai



project. The reduction in growth rate this represents is such that oysters require an average of 25 months to reach market size and all are sold as Grade B. Extending the growing period into a third year pushes back all revenue receipts by 12 months compared with the other investments appraisals shown in Figure 7.10. This project loses approximately £4,000 more than the 'key appraisal'. The results show that the commercial viability of the proposal at this site is very sensitive to a fall in ambient seawater temperatures.

O. edulis grown at Emsworth

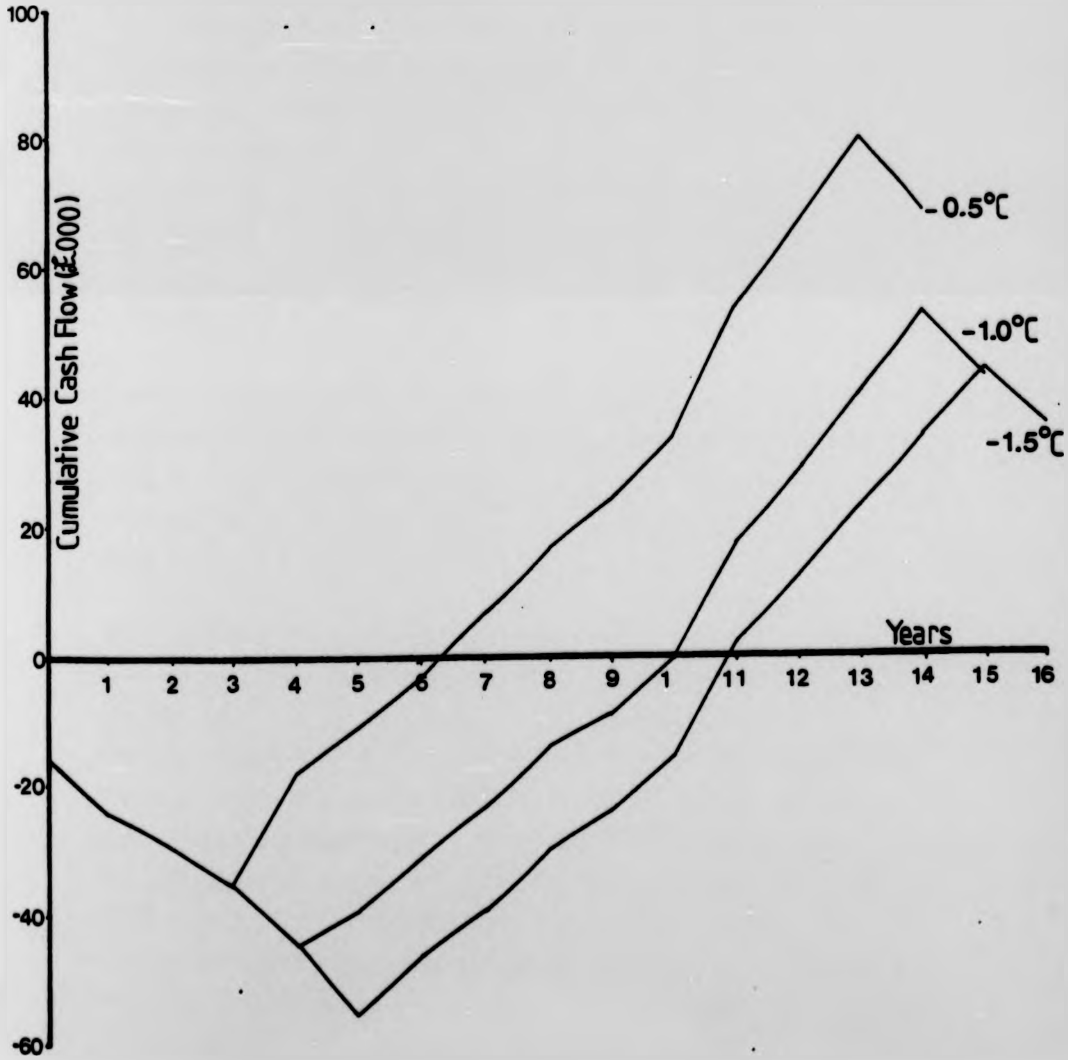
No attempt has been made to investigate the effect of temperature increases at the Emsworth site. No suitable data was available on the performance of this species at high temperatures and the growth model is considered to be non-applicable for temperatures above 19°C.

Temperature reductions have been considered and are plotted in Figure 7.11. The longer ongrowing period of this species serves to accentuate any differences brought about by any change in the seawater temperatures. In examples where temperature reductions are tested only Grade 2 *O. edulis* are predicted. In the 'key appraisal' 72.4% of the marketed oysters are Grade 1. Each 0.5°C temperature reduction at this site increases the ongrowing period by almost one year, i.e.

Temp. regime	No change 'key appraisal'	- 0.5°C	- 1.0°C	- 1.5°C
Ongrowing period in months	36 mths	47 mths	58 mths	70 mths

The effect of pushing revenue receipts further into the future is illustrated by the reduced IRR and increased payback periods (Table 7.7). At the lowest temperature regime considered survival to market size exceeds 50% and the final net cash flow accrued is £35,595. This is greater than any of the appraisals tested for *C. gigas* but the sustained negative cash flow for much of the project life would deter any disconcerning investor.

Figure 7.11 **The effect of varying the temperature regime for the culture of *Ostrea edulis* at Emsworth**



O. edulis grown at Menai

At this site a full set of temperature increases and a temperature decrease of 0.5°C are considered. Other temperature decreases were not considered justified since the time required for the oysters to attain market size would be too great. At - 1.0°C below the Menai temperature regime *O. edulis* requires eight years to reach 70 grammes.

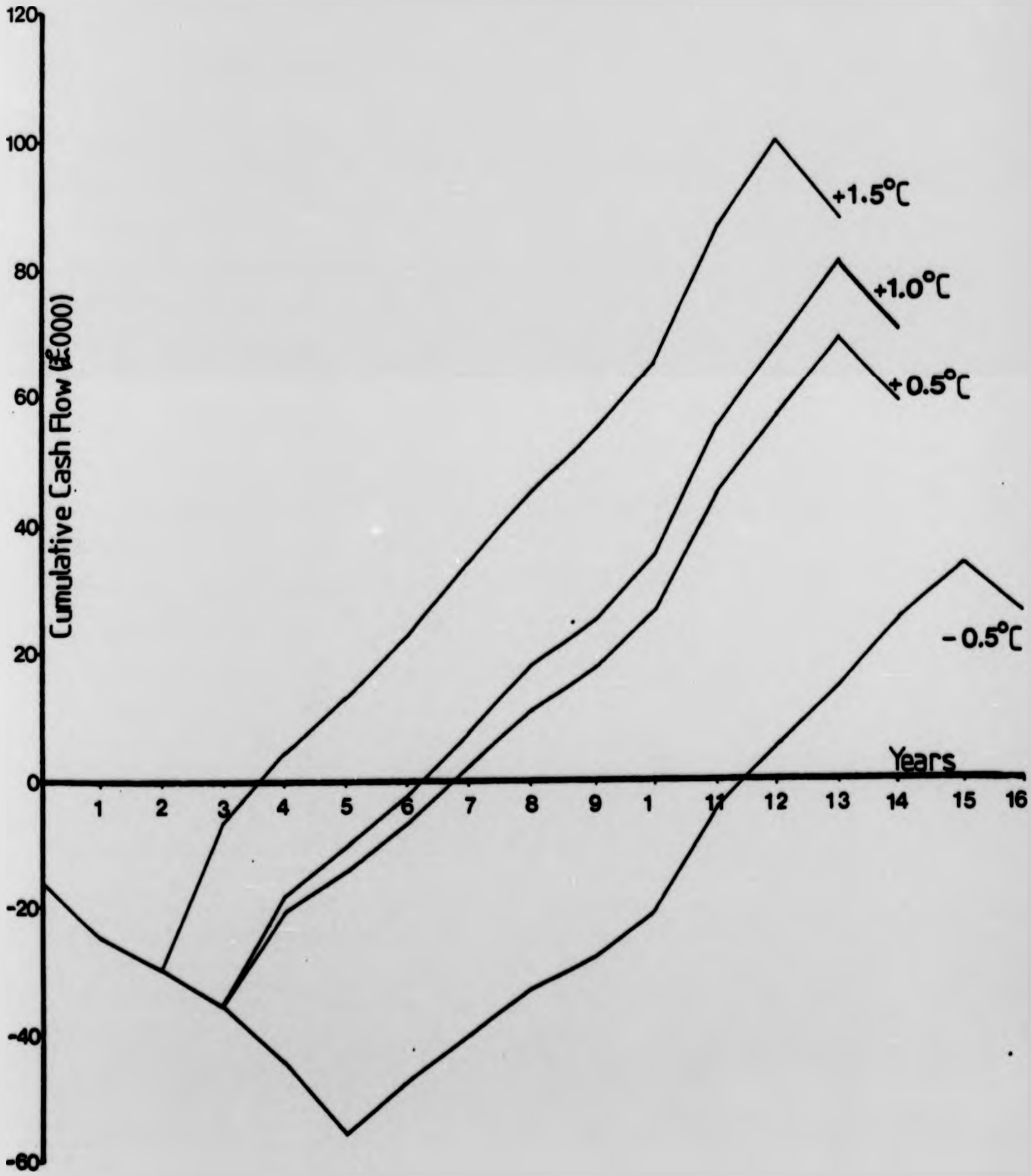
In all the appraisals shown in Figure 7.12 only Grade 2 oysters are produced. As before the higher the temperature regime employed the greater the return on investment due to the faster growth encountered, i.e.

Temp. regime	No change 'key appraisal'	+ 0.5°C	+ 1.0°C	+ 1.5°C
Ongrowing period in months	64 months	52 mths	45 mths	39 mths

Growth patterns differ between the two sites but the + 1.5°C temperature regime at Menai has a similar temperature distribution to the 'key appraisal' for *O. edulis* at Emsworth. This is reflected in similar cumulative net cash flows for these two examples.

The very favourable returns on investment shown in the + 1.5°C example is attributable to the growth exhibited by oysters planted out in July (the last of the three months used). Oysters planted out in this month grow rapidly during the first growing season due to the combination of small spat size and high seawater temperature. If this month was omitted and spat only planted out in May and June the IRR would be reduced to 18.9% with a payback period of 6 yrs 1 month. However, such a plan would produce 50,000 marketable oysters in two consecutive months and would present problems with marketing. The inclusion of July planted spat may yield over-optimistic rates of returns in this case but presents a more realistic marketing strategy.

igure 7.12 <u>**The effect of varying the temperature for the culture of *Ostrea edulis* at Menai**</u>



7.3.5 The effect of varying Selling Price

The approach adopted has been to investigate the effect on 'key appraisal' IRR of both increases and decreases in the selling price of marketable oysters. As the predicted yield in each appraisal does not vary it is possible to monitor the effect of price changes by merely varying the Total Annual Revenue, i.e.

Revenue = Yield * Selling Price.

The results obtained are summarised in Table 7.8 and plotted graphically in Figures 7.13 and 7.14. All the graphs show that the return on investment increases as the selling price is increased. At both sites the results indicate that *C. gigas* projects are the most responsive to changes in selling price. In all but one of the appraisals performed proposals to cultivate *O. edulis* yield a higher IRR and in all cases gives a greater monetary return than *C. gigas* (Table 7.8). By comparing the two temperature regimes it can be seen that for both species a larger return on investment is realised when the oysters are cultivated at the warmer site, Emsworth. For example if the selling price is increased 20% then *O. edulis* cultivated at Emsworth yielded an IRR of 28.7% but only 12.8% at Menai for an operation to produce 100,000 mature oysters per annum in each case.

The IRR gives no indication of the difference in project value. An increase of 20% in the selling price of both species at Emsworth (Figure 7.13) results in very similar IRR but conceals the fact that the value of the *O. edulis* project is nearly three times that for cultivating *C. gigas*, i.e.

20% increase in Selling Price of oysters grown at Emsworth

Species	IRR (%)	Cumulative Net Cash Flow (£)
C. gigas	25.0	£45,009
O. edulis	28.7	£133,695

If the equipment and labour inputs alone determined price then at each site the rates of return for both species should be similar. This is certainly not the case as a premium price is given for the Native Oyster, *O. edulis*. The reasons for this

Table 7.8 **Summary of Results for selling price variation**

% change in Selling Price	EMSWORTH						MENAI					
	C. gigas			*O. edulis*			*C. gigas*			*O. edulis*		
	IRR (%)	Payback Period	Cumulative net cash flow (£)	IRR (%)	Payback Period	Net Cash Flow (£)	IRR (%)	Payback Period	Net Cash Flow (£)	IRR (%)	Payback Period	Net Cash Flow (£)
+ 40	30.6	2yr 5mth	55,590	33.5	4yr 1mth	167,947	17.8	4yr 2mth	29,900	16.4	7yr 2mth	88,026
+ 30	29.7	3yr 1mth	60,092				13.8	6yr 1mth	22,326	14.6	7yr 4mth	74,547
+ 20	25.0	3yr 3mth	45,009	28.7	4yr 3mth	133,695	9.5	7yr 1mth	14,751	12.8	8yr 2mth	62,873
+ 10	20.2	4yr 1mth	34,910				4.4	9yr 3mth	6,198	10.8	9yr 1mth	51,202
+ 5							1.8	10yr 4mth	2,411			
- 10	9.5	7yr 1mth	14,713	20.2	5yr 4mth	82,207				8.0	10yr 2mth	35,739
- 20	2.6	10yr 2mth	3,644							5.3	10yr 9mth	22,154
- 30			(5,726)	14.1	7yr 1mth	51,930				2.2	12yr 1mth	8,567
- 50				5.9	10yr 4mth	19,115						

Figure 7.13 The effect on project internal rate of return of varying the selling price of oysters grown at Emsworth

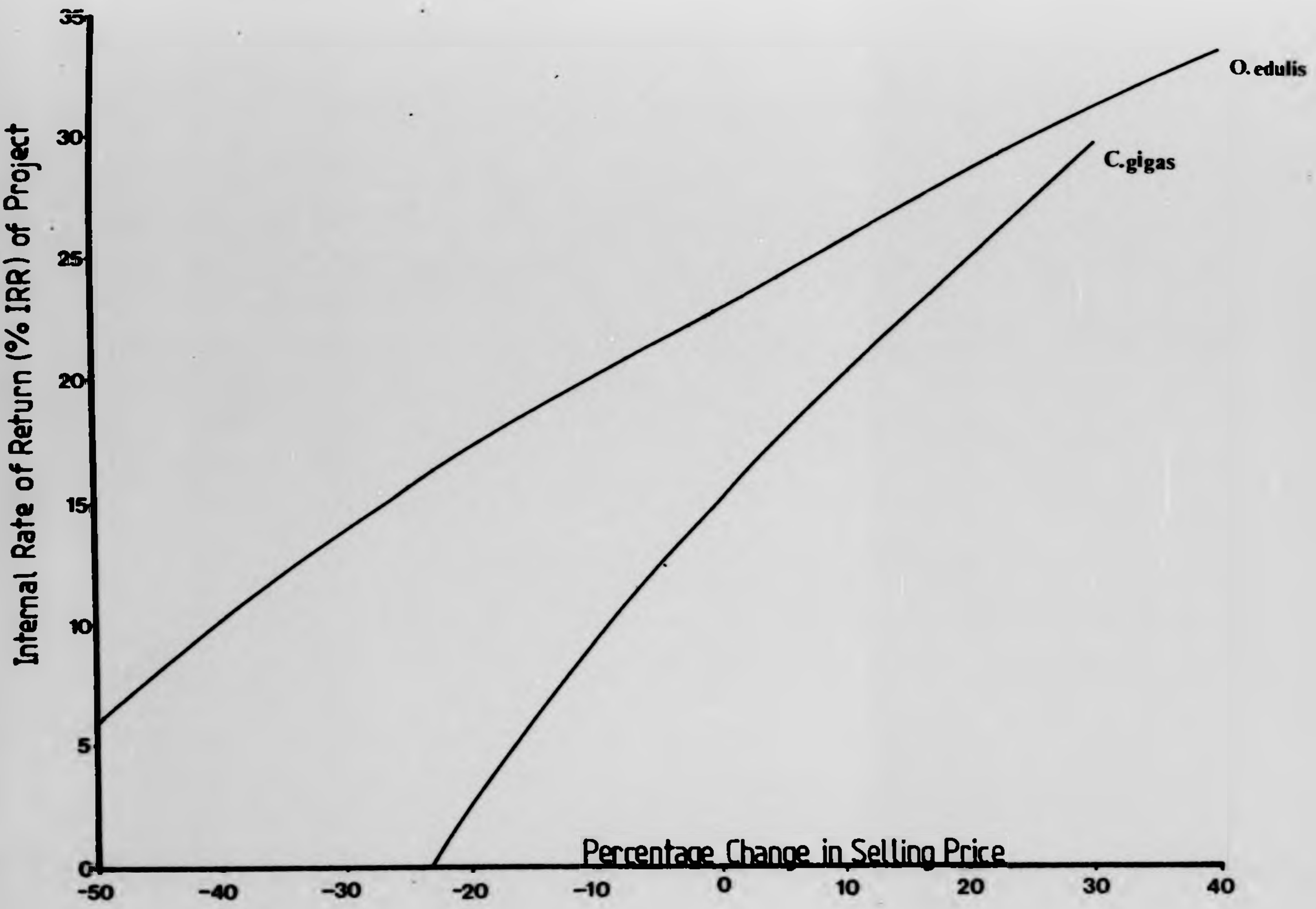
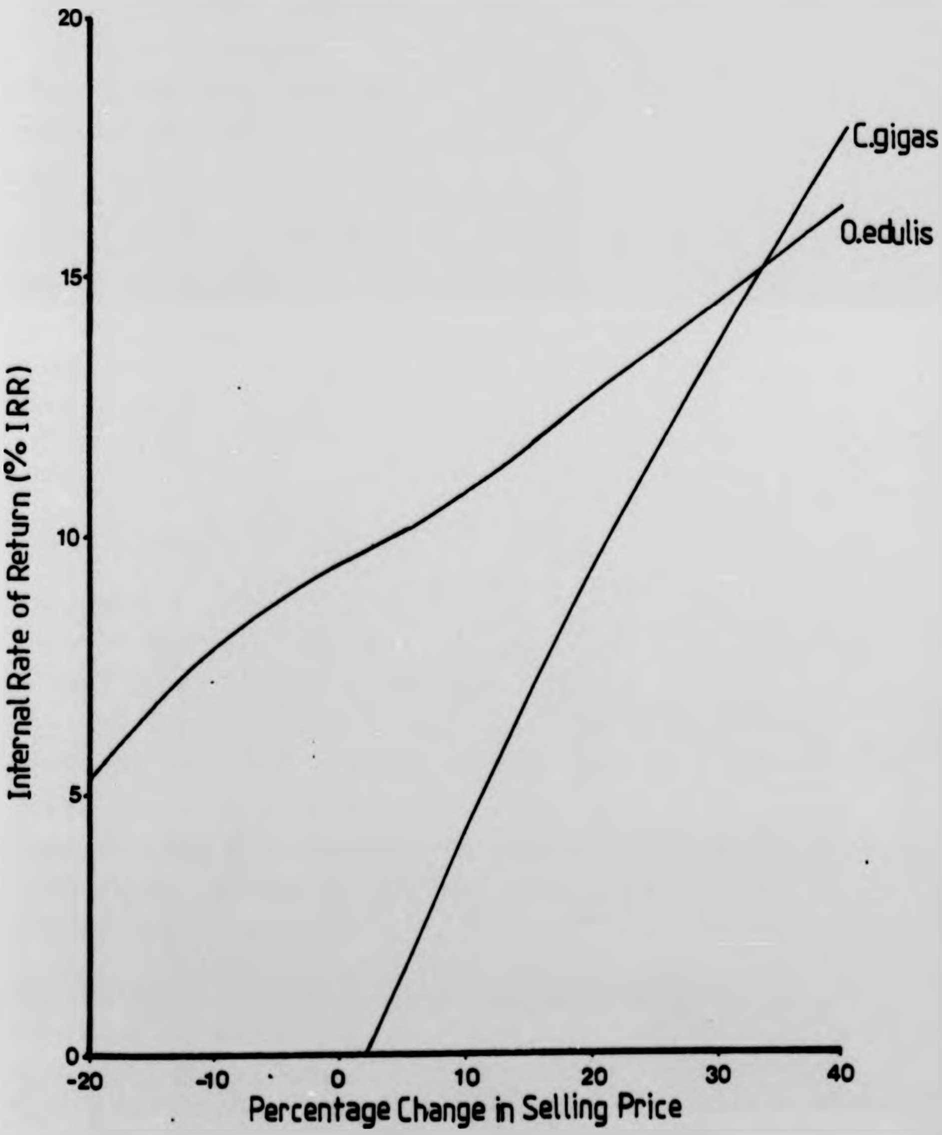


Figure 7.14 **The effect on project internal rate of return of varying the selling price of oysters at Menai**



may be partly traditional as this oyster has long been regarded as a luxury food item. The slower growth rate of this species increases the risks to investment and ties up capital for longer. The higher price it commands may include an element to account for this.

The 'key appraisal' for *C. gigas* grown at Menai showed a cumulative net cash flow of £-397 and on this basis the project would be rejected. The wholesale selling price of a 70 gramme *C. gigas* is given as 11p and a 20% rise in price would be sufficient to give a positive return on investment of £6,198. Even with this increase the price of each oyster would only be half the price of a comparable sized *O. edulis*.

With the current selling price of *C. gigas* there is little scope for any price reduction. The cultivator who produces only this species must ensure that his site gives the maximum potential yield, his costs are minimal and that a sufficiently large, available market is established.

7.3.6 The Effect of Varying the cost of Production

The results plotted in Figures 7.15 and 7.16, and summarised in Table 7.9 show that the project Internal Rate of Return decreases as the pre-tax total annual costs are increased. As with Selling Price it is *C. gigas* which is the more responsive to changes at both sites. For each species the response to cost changes is greater at Menai. These observations may be explained in terms of the growth differences and selling price differences of the oysters since their production costs are very similar.

Projects where *C. gigas* is cultivated have little scope for increasing costs at this scale of operation. At Menai the cultivation of this oyster is not economically justified and at Emsworth an increase in costs of 30% renders this proposal commercially unattractive (Figure 7.15).

In contrast a substantial increase in production costs still yields a positive return on investment for *O. edulis* at both

Table 7.9 <u>Summary of Results for production cost variation</u>

% change in Costs	EMSWORTH						MENAI					
	C. gigas			*O. edulis*			*C. gigas*			*O. edulis*		
	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	IRR (%)	Payback Period	Net Cash Flow (£)	IRR (%)	Payback Period	Net Cash Flow (£)	IRR (%)	Payback Period	Net Cash Flow (£)
+ 50				10.9	8yr 1mth	57,858						
+ 40										2.2	12yr 1mth	12,305
+ 30			(176)	15.3	6yr 4mth	75,915						
+ 20	4.6	9yr 3mth	7,833							5.9	10yr 7mth	30,818
+ 10	9.9	7yr 1mth	16,922	20.3	5yr 4mth	91,608				8.1	10yr 2mth	40,168
- 10	20.8	4yr 1mth	32,430	27.0	4yr 4mth	109,974	5.6	9yr 6mth	7,548	11.8	8yr 3mth	50,980
- 20	27.2	3yr 2mth	40,045				11.9	6yr 3mth	15,423	13.7	7yr 5mth	55,105
- 30	34.7	2yr 5mth	47,657	34.3	3yr 10mth	12,110	19.0	4yr 2mth	23,035	16.8	7yr 1mth	62,814
- 40							27.2	3yr 2mth	30,613	20.4	6yr 3mth	70,491

Figure 7.15 <u>**The effect on project internal rate of return of varying the cost of production for a unit to produce 100,000 oysters per annum at Emsworth**</u>

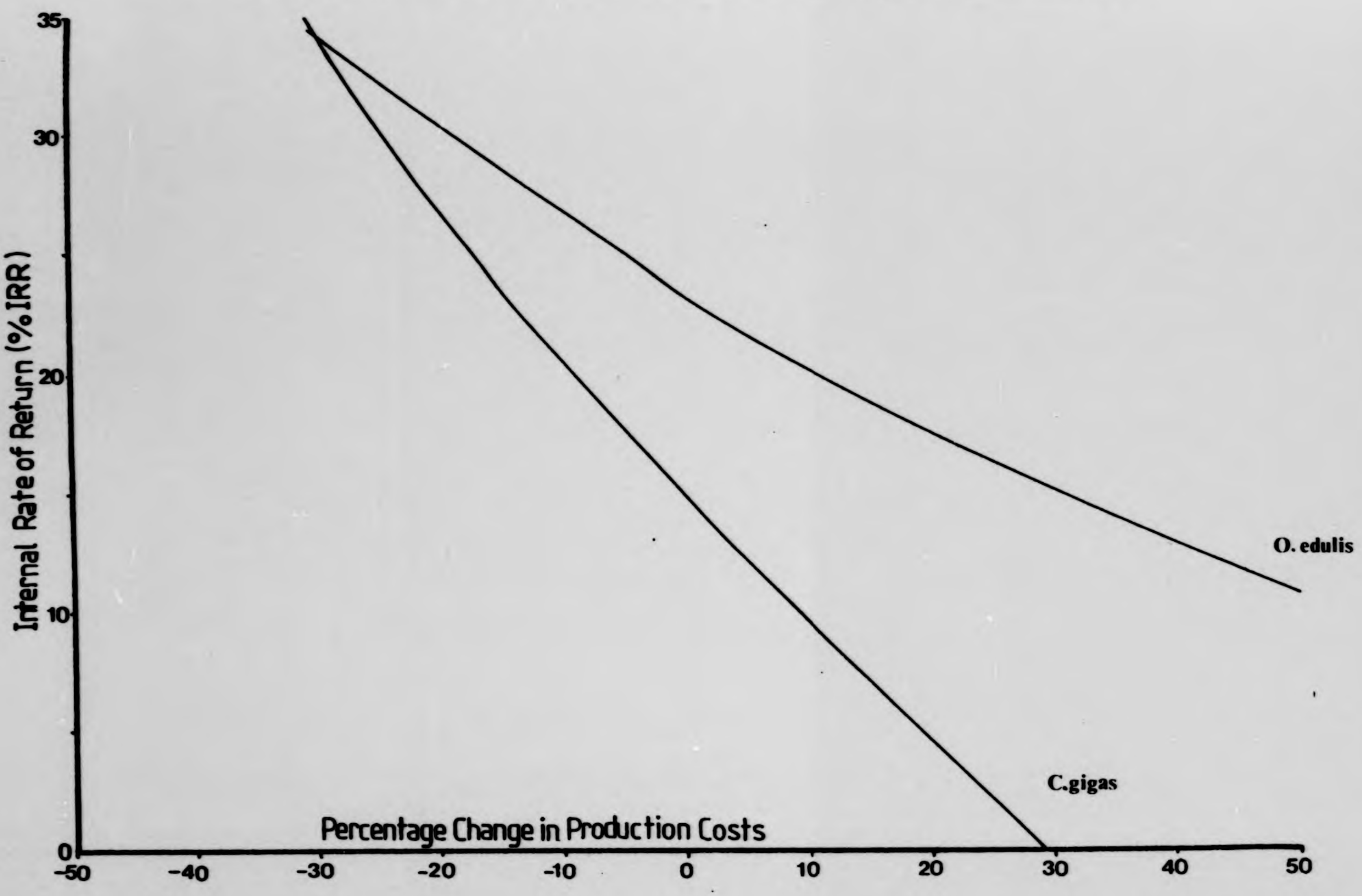
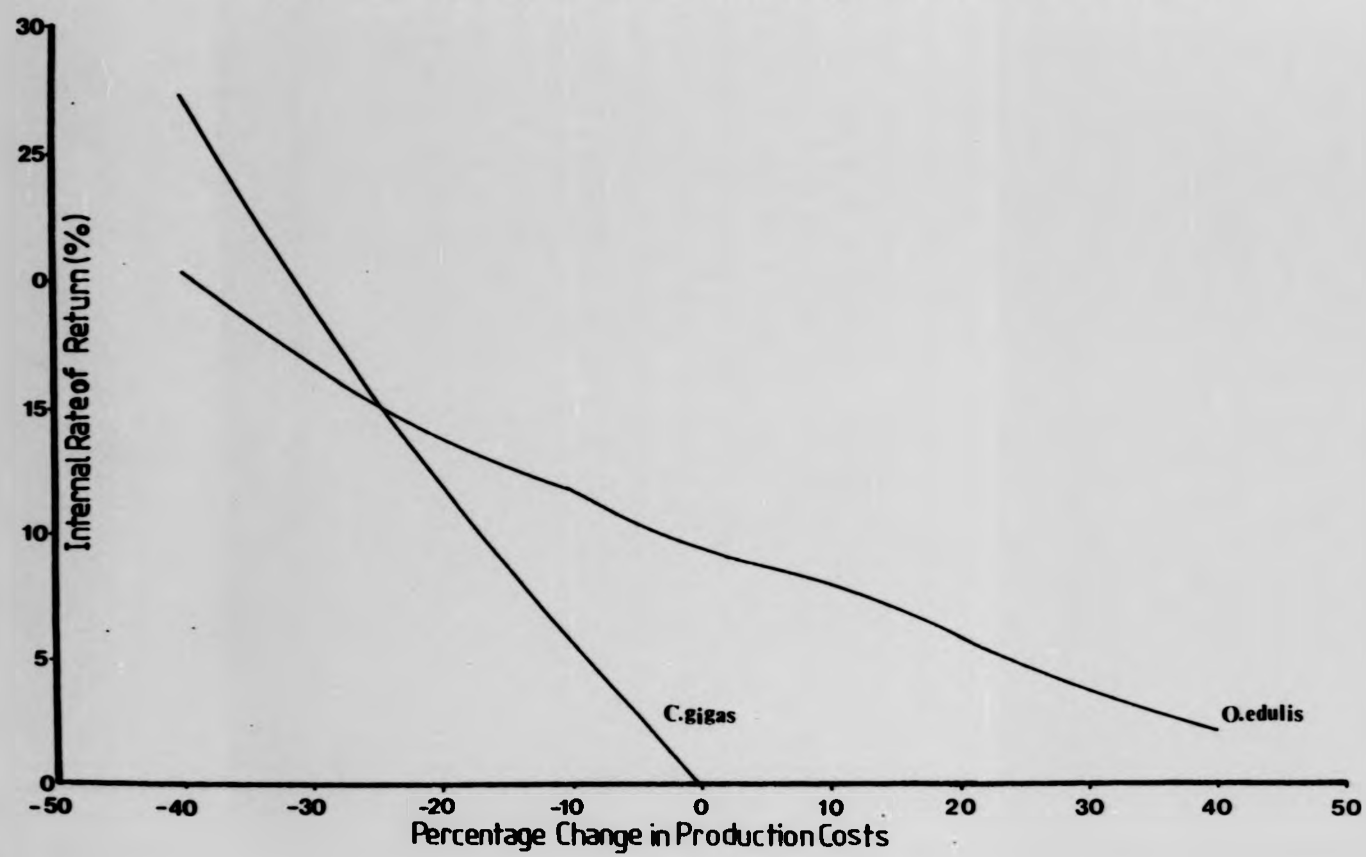


Figure 7.16 The effect on project internal rate of return of varying the cost of production for a unit to produce 100,000 oysters per annum at Menai



sites (Table 7.9). The financial attraction of this species arises from the premium price it commands without any significant increase in the level of investment required. Weighed against this is the longer ongrowing period which pushes further into the future the point when revenue begins to accrue.

For completeness in the analysis certain cost reductions have also been considered. However, the opportunities for any significant cost reductions in an operation of this scale are negligible. The results do show that even small cost reductions have a favourable effect on the project viability. At Menai a 10% cost reduction on the cultivation of *C. gigas* results in a positive return of 5.6%. This result suggests that the cultivation of this oyster on a part-time basis might be commercially attractive at this site.

The main operating cost in these investment appraisals is the labour input. This has been included at Agricultural Wage Rates which are below the current National Wage levels. The reasons for using these rates have been discussed earlier. Circumstances where additional labour for harvesting, regrading or where other wage rates would be applicable could arise. In such circumstances the labour cost will increase. As an indication of the likely effect on IRR an example has been considered where the labour input has been doubled for the 'key appraisals' at Emsworth. Similarly an area where equipment costs could increase would be in the estimate of capital costs in year 0. An example where the initial outlay has been increased by 50% has been calculated for the same 'key appraisals'. The investment appraisal results generated are shown below in Table 7.10.

Table 7.10 The Effect of Specific Cost increases at Emsworth

	Species	IRR	Payback	Cumulative Net Cash Flow (£)
(a) Labour (100% increase)	*C. gigas*	-	-	£(12,689)
	O. edulis	13.6%	7yr 2mth	£ 61,846
(b) Capital Expenditure (50% increase)	*C. gigas*	8.2%	7yr 2mth	£ 16,943
	O. edulis	18.5%	5yr 4mth	£ 91,487

It is not possible to draw any conclusions from just two examples but it does serve to indicate the need for accurate estimates of costs to be prepared before any cultivation is attempted. In the case of *C. gigas* the matching of production to labour availability in this one man operation could mean the difference between success and failure. The operator in this example clearly cannot afford to employ a second full-time worker.

7.3.7 Increasing the Scale of Operation

All investment appraisals in this analysis have been based on a production of 100,000 mature oysters per year. At the time of writing only Cuan Sea Fisheries of Northern Ireland significantly exceeds this production level.

This output represents the maximum number of oysters that one man could cultivate and market. Any significant increase in production would necessitate the employment of at least one additional worker and increased expenditure on equipment.

Any attempt to cost out larger systems is speculative and the costs adopted are based to an extent on value judgements. Large intertidal systems using 'parcs' are in operation on the Continent (Korringa, ibid). This method of culture is, however, extensive rather than intensive and is very labour intensive. Sites where such techniques would be viable in the UK are not readily identifiable. The costing of such units has little to offer in attempting to study large units using tray culture in this country.

It is possible that at some future date large production units will come into operation and because of their size they may be able to achieve economies of scale. To investigate this possibility two sizes of operation have been costed producing 250,000 and 500,000 mature oysters per annum respectively.

In scaling up the operation the costs have been increased in line with production from the estimates given in Chapter Six. The labour input required has been estimated as follows:

	Number of oysters produced per annum	
	250,000	500,000
Labour force*	1 foreman 1 stockman	1 foreman 2 stockmen

* Labour cost derived from Table 6.5.

As the scale of the venture is increased the ongrower is likely to perform a more supervisory and administrative role and is included as a foreman. Using these assumptions these two scales of operation have been studied for each 'key appraisal', and the results presented graphically in Figures 7.17 - 7.20 and summarised in Table 7.11.

A consistent pattern is evident from these results. Increasing the scale of production significantly increases the net cash flow of the project and increases the IRR. This would suggest that in these examples there are economies of scale. Increasing the scale of operation permits a higher utilisation of ongrowing equipment. Also capital expenditure on certain items, for example buildings, does not increase with an increase in the scale of operation.

However, increasing the scale of operation does not reduce the inherent risks of this type of investment. Indeed cultivating such a large number of oysters at high densities lays the project open to high financial losses caused by bad weather or disease. The decimation of the French oyster industry in the late 1960s and early 1970s by Aber Disease serves as a stark reminder of how delicate the balance between success and failure is with regard to shellfish culture.

Spreading production over several sites would minimise the risk of large stock losses but increase the costs of labour and transport. Furthermore it might be difficult to acquire suitable sites in terms of habitat and security within a suitable area given the competition which exists for the use of the coastline.

Table 7.11 <u>**Increasing the Scale of Operation for oyster cultivation unit**</u>

SPECIES	SITE	Size of Production Unit					
		250,000 per annum			500,000 per annum		
		IRR (%)	Payback Period	Cumulative Net Cash Flow (£)	IRR (%)	Payback Period	Cumulative Net Cash Flow (£)
C. gigas	Emsworth	23.1	3yr 3mth	74,552	31.3	2yr 5mth	190,938
	Menai	12.1	6yr 3mth	38,671	16.3	4yr 3mth	88,649
O. edulis	Emsworth	29.5	4yr 3mth	308,622	34.0	4yr 1mth	603,586
	Menai	11.3	9yr 1mth	119,895	16.6	7yr 2mth	313,410

Figure 7.17 The effect on project cash flow of increasing the size of a unit to produce *Crassostrea gigas* at Emsworth

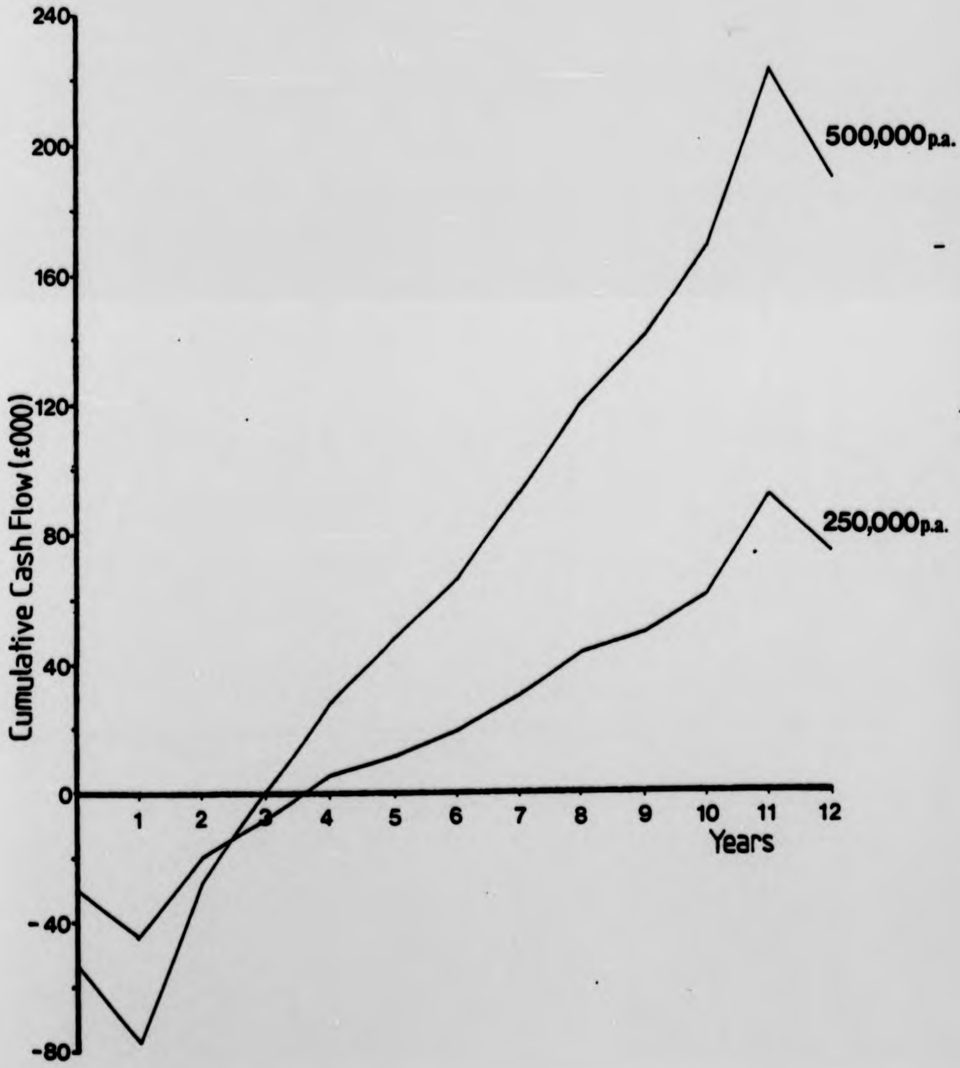


Figure 7.18 <u>The effect on project cash flow of increasing the size of a unit to produce *Crassostrea gigas* at Menai</u>

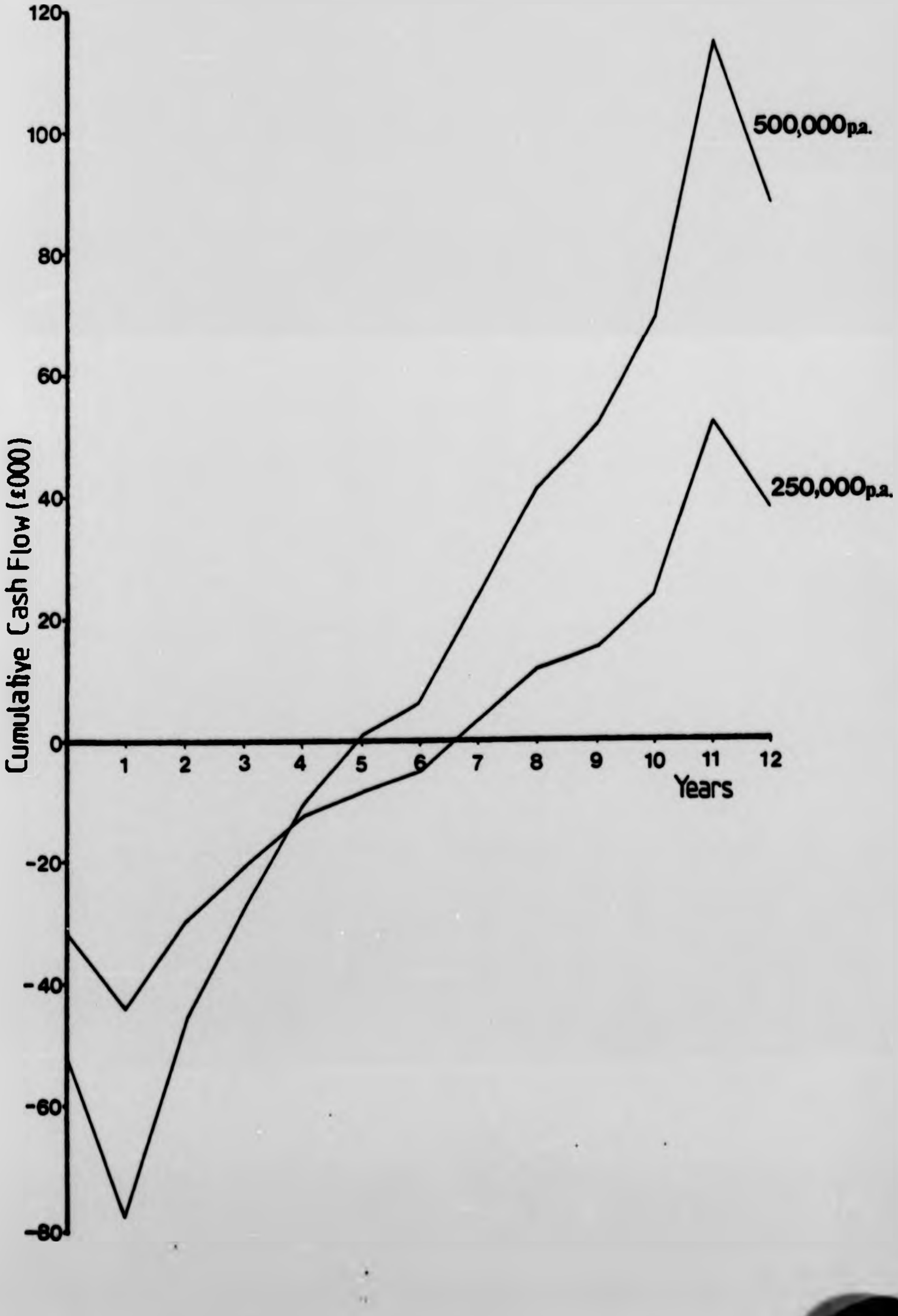


Figure 7.19 <u>The effect on project cash flow of increasing the size of a unit to produce *Ostrea edulis* at Emsworth</u>

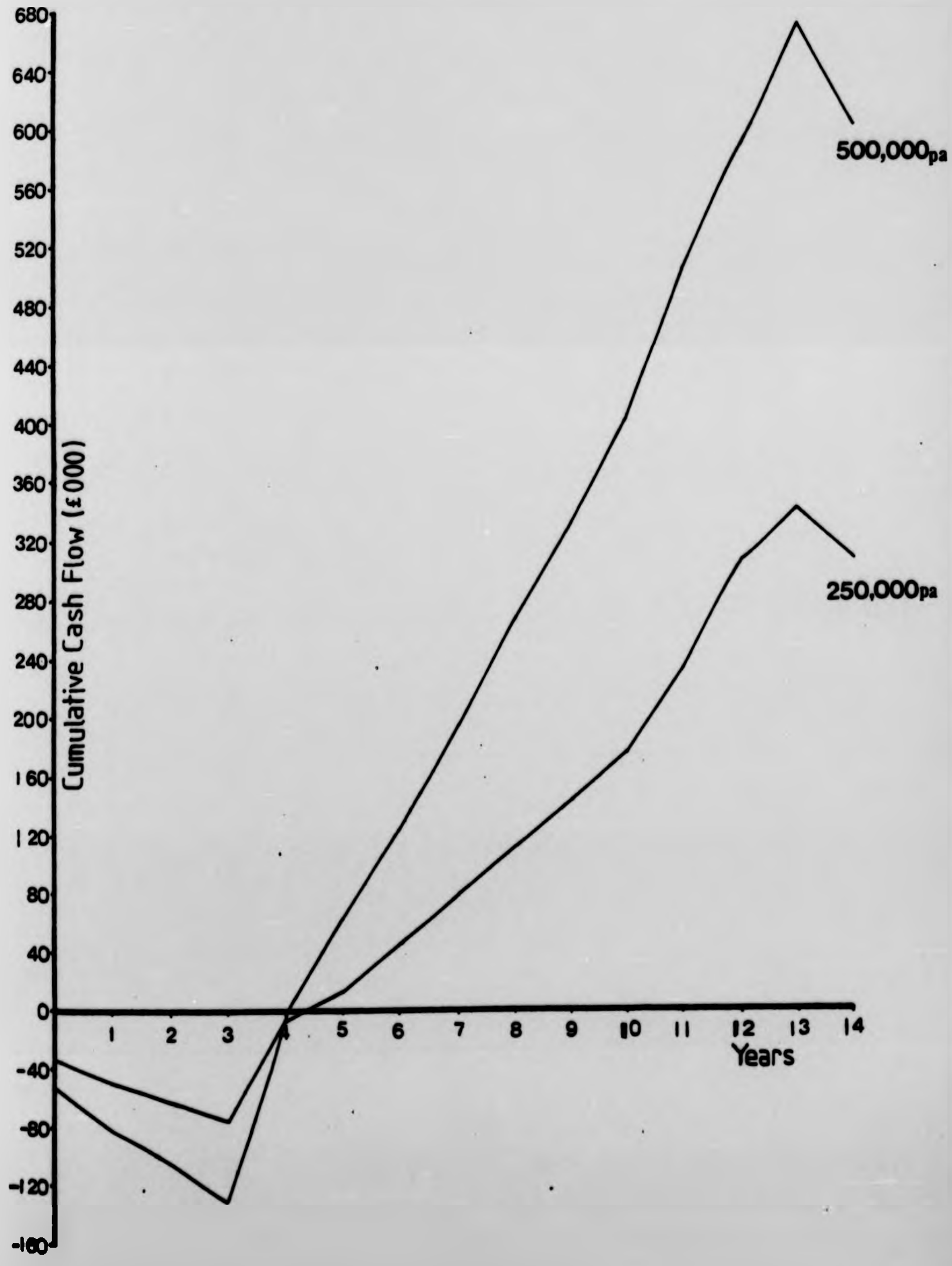
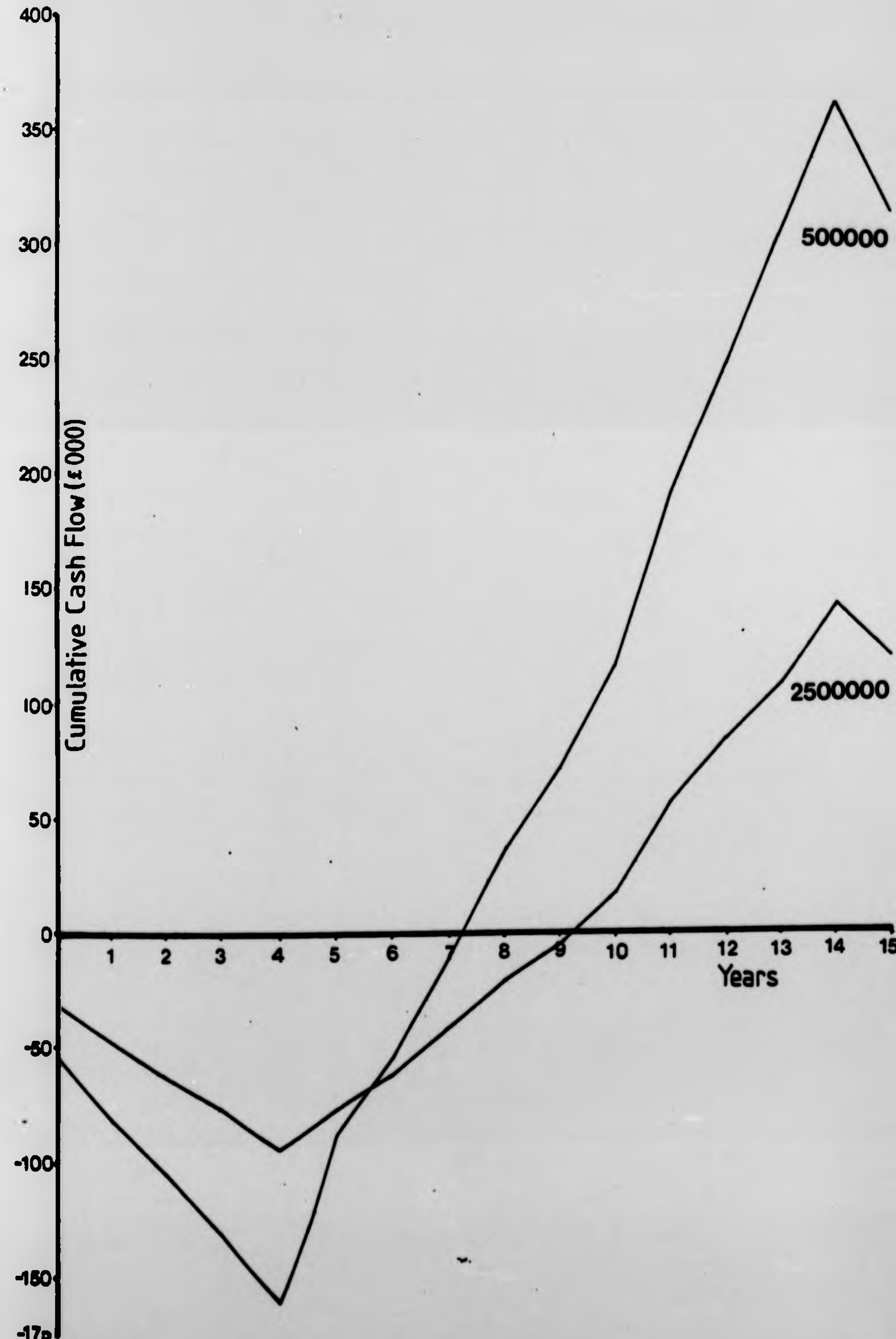


Figure 7.20 The effect on project cash flow of increasing the size of a unit to produce *Ostrea edulis* at Menai



In the example of a production of 500,000 p.a. the accummulated cash outflow in the early years before any revenue is accrued may be as high as £160,000 with a payback period of 9 years 1 month (Figure 7.20). When viewed in these terms financial institutions might be recitent to invest in what is fundamentally a high risk business.

In view of the points raised above it seems probable that oyster cultivation for the foreseeable future will continue to be centred on small units.

7.3.8 The use of Suspended Culture techniques

Intertidal culture has been adopted throughout this analysis since it is the type of system from which the growth data used in the model was derived and in an attempt to minimise costs. Other ongrowing techniques exist and are used commercially by some operators. The most successful of these is to employ some form of suspended culture (Chapter Three). One of the main claims for suspended culture is that it facilitates a faster growth rate which justifies the higher capital costs associated with such systems.

To provide a comparison with the costings derived for intertidal culture an attempt has been made to evaluate a system using Knapdale trays to grow 0.1 gramme spat to 5 gramme and then Lantern Nets to grow the oysters up to 70 grammes. Only the temperature regime at Emsworth has been employed in an attempt to simulate the higher growth rate claimed for suspended culture. No worker, to the author's knowledge, has been able to quantify this growth advantage hence it is not possible to derive a specific temperature regime to mimic the effect.

These investment appraisals differ only with respect to the form of ongrowing tray or net used and the deletion or addition of items specific to either type of cultivation. For example the cost of protective fencing has been omitted in these examples. It is assumed that the boat, at present included, will be adequate for this scale of operation and that no additional labour cost will be incurred. Any increased labour requirement will be offset by the greater accessibility of the oysters.

The results of the appraisals are shown graphically (Figure 7.21) and are summarised in Table 7.12.

Table 7.12 The use of Suspended Cllture to produce 100,000 oysters per annum

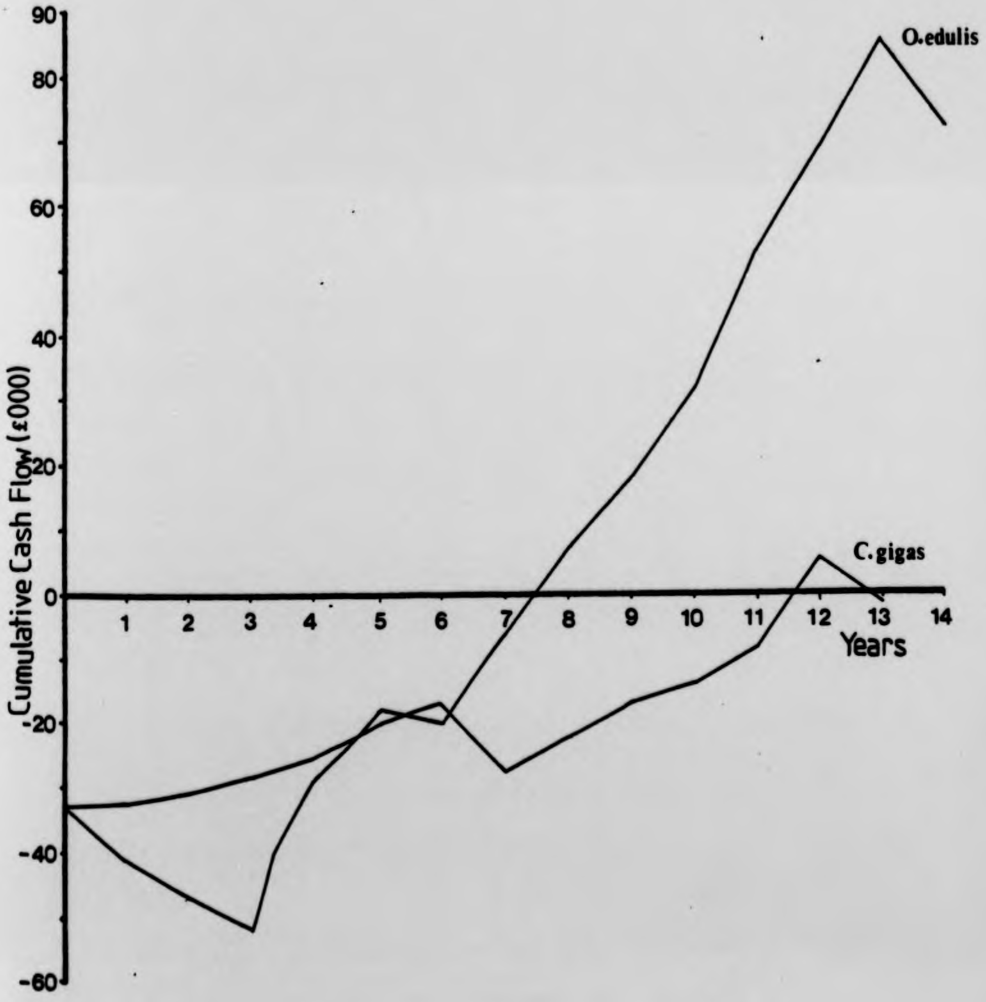
Species	IRR (%)	Payback Period	Cumulative net cash flow (£)
C. gigas	-	-	£(1,321)
O. edulis	13.0	7yr 3 mth	£72,306

The result for *C. gigas* shows a loss over the project life of £1,321 compared to a positive return on investment of £24,820 with the use of intertidal trays. Similarly the IRR of the *O. edulis* project has been reduced when compared to the 'key appraisal'.

The reason for this fall in value is indicated on the graphical plot (Figure 7.21). The rising cumulative net cash flow in both instances is arrested and drops back in year 6. This represents the point where replacement of lantern nets and buoys is required to replace equipment which is fully depreciated. The cost of the required equipment is £15,946 which is greater than the initial capital expenditure for intertidal tray culture. The inclusion of this cost in year 0 and year 6 accounts for the marked reduction in commercial viability.

Certain of the assumptions made in this particular investment appraisal could be challenged. It is not necessary to maintain oysters in lantern nets till market size is attained. Some growers only use lantern nets at certain stages of growth after which the oysters may be planted out on the sea bed.

Figure 7.21 Cumulative net cash flows of projects to produce 100,000 oysters per annum at Emsworth by the use of suspended culture



The decision to adopt lantern nets culture to 70 grammes is based on the practise in Japan where the nets originated and published work in the United Kingdom (Briggs, ibid). A five year working life has been adopted for these nets although they are a relatively recent introduction to the United Kingdom and little published information exists on their durability. However, given that they are nets it appears reasonable to depreciate them on a similar basis to the much more robust NWP trays.

In conclusion it would seem that within the defined scope of this appraisal the technique of intertidal tray cultivation of oysters is the more inexpensive and offers the best opportunity of securing a positive return on investment for the ongrower.

7.4 EVALUATION OF THE ANALYSIS

This analysis has demonstrated that, given accurate cost estimates, the pattern of expenditure and the amount and timing of the return on investment from oyster cultivation may be forecasted accurately. The results show how sensitivity analysis may be used to quantify the effects of the interplay of environmental, biological and economic factors. The commercial viability of oyster cultivation has been shown to be dependent on the species and the temperature regime under which the shellfish are grown. Changes in mortality rate and spat size have a greater effect upon the financial returns of an enterprise when there is a long ongrowing period in the sea.

For similar scales of investment the financial yield is considerably higher from the cultivation of the Native Flat Oyster, *O. edulis*. This is attributed to the premium selling price this oyster commands in the market place. The economics of producing the Pacific Oyster, *C. gigas* have been shown to be very sensitive to changes in both production costs and selling price.

The calculation of the expected return on investment provides only one of several criteria upon which the potential cultivator should base his investment decision. Invariably it is the investor who demonstrates a clear appreciation of all aspects of his proposal and has the motivation to see the project through who succeeeds. Identification of a market gap, the determination to exploit it and careful planning are essential first steps prior to the computation of expected financial returns.

When this is completed the investor may turn his attention to establishing an acceptable rate of return. In this analysis proposals which give only negative net cash flows would be the first to be eliminated. The project to produce 100,000 *C. gigas* per annum at Menai would be rejected. In view of the possible variation in oyster growth rate projects which require several years to produce marketable oysters can also be eliminated. Estimates quoted in Table 5.1 show that acceptable ongrowing periods for oysters are:

C. gigas	1 - 2 years
O. edulis	3 - 6 years

All projects where the ongrowing period exceeds these figures could be rejected since revenue receipts would not commence until years 3 and 7 respectively. In cases where loan assistance is given by bodies such as the Highlands and Islands Development Board the first repayment is due in the third year of the project. Under such circumstances the investor must select from proposals which begin to accrue revenue prior to this date.

It has been suggested that fish farmers must not aim at a return of less than 30% on total capital employed (McAnuff, ibid). The results of this analysis show that projects with lower internal rates of return may be acceptable. Tested proposals which have an acceptable ongrowing period are associated in the analysis with a survival rate up to market size of over 70%. These projects all have payback periods of less than or equal to half the total project life. For example the proposal to produce

100,000 *O. edulis* per year from 0.1 gramme spat has a payback period of 5 years 1 month and a project life of 14 years (Figure 7.3). The Internal Rate of Return of these projects falls in the range 15 - 30%. As all appraisals are based on constant prices these results are 'real' rates of return and are high compared to other investment opportunities. The author proposes that given the criteria discussed above an IRR of 15% or over is an acceptable hurdle rate of return for the relatively untried business of oyster cultivation.

Using these criteria a temperature regime 0.5°C greater than that at the Menai site would be sufficient to make the production of 100,000 *O. edulis* per annum viable. An increase of 1.0°C is adequate to make the production of 100,000 *C. gigas* per annum commercially attractive. If cost reductions could be achieved a decrease of 25% would yield a 15% IRR for both species at the Menai site. Alternatively, if the ongrower could achieve a 33% increase in revenue the target IRR of 15% would be achieved at Menai.

The investment appraisals clearly demonstrate that the cultivation of oysters under certain of the conditions investigated is a commercially viable venture. The acceptance or rejection of a project must be based on an independent appraisal of each proposal. Sensitivity analysis on the results of the basic appraisal is essential to determine the vulnerability of the enterprise to change. To ensure a wide range of return on investments emphasis in this study has been placed on units producing one species of oyster. In a commercial venture a species mix may be desirable. It is proposed that in the early years of a project emphasis be placed on the faster growing *C. gigas*. The rapid turnover of capital with this species would ease the cash flow situation in these years. Once a sound financial base is established more attention will be paid to the cultivation of *O. edulis* which commands a higher selling price. The similarities in culture technique employed for the two species would allow such a change for a minimum increase in expenditure.

There exist important differences between the two types of oyster with regard to growth rate, marketing season and selling price. There is, at present, considerable scope for extending the approach adopted in this study to consider production scheduling. The dynamic programming technique is a method which could be employed to derive production schedules to optimise profit under various production and marketing constraints. Further refinements of the model including the introduction of variation in growth rate could also be considered. This is obviously an avenue which could be explored in any further work.

Any new venture needs finance and this requirement will be gauged more easily if cash flow forecasts are prepared. All too often projects underestimate the amount of capital required. It has been suggested that the investor should initially budget to have sufficient finance to cover the project for a period equivalent to double the oysters' growth time (O'Brien, 1979). In this analysis this represents a sum of £25,000 at the start of a project to produce 100,000 *C. gigas* per annum at Emsworth and is a good rule of thumb for the investor to apply.

The investor must appreciate the uncertainty associated with the future and match production to the changing needs of his customers. Investment appraisals provide only a static picture of the future. Regular re-appraisals of financial targets will facilitate control over costs and indicate the success with which financial goals are achieved. In aquaculture as with business in general the utilisation of professional and technical advice and time spent on financial planning will yield great returns in the long term for a minimum of expended effort.

Chapter 8

THE MARKETING OF OYSTERS IN THE UNITED KINGDOM

8.1 BACKGROUND

In the nineteenth century oysters were a staple part of the diet of the poor sector of the community. In the present century there has been a radical change in the market for oysters. Production has declined dramatically due to overfishing and mass mortalities from 40 million per annum in 1920 to 5-6 million per annum at the present time. One effect of this transformation has been to generate a segmented shellfish market with oysters and lobsters as highly prized luxuries; whelks, winkles cockles and mussels considered as 'poor man's fare' and scallops, scampi and crabs occupying an intermediate position.

The modern market is very demanding, quality and size must be consistent and supply steady during the season. Cultivation and the discovery of oyster stocks in the Solent have brought about an upturn in production over the last decade. There exists a ready market on the Continent for British oysters and many Solent oysters are exported.

This chapter attempts to describe the present status of both *Ostrea edulis* and *Crassostrea gigas* marketing in the United Kingdom and to suggest some directions in which the market for cultivated oysters may most fruitfully be expanded. Inevitably much of the discussion will centre on the sale of the Native Flat Oyster given the long tradition of this fishery and its importance compared to other species. It is into this market that virtually all Pacific Oysters are at present sold.

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8.2 SEASON

Traditionally oysters are deemed fit for human consumption only if there is an 'r' in the name of the month. This has a firm biological basis since *O. edulis* breeds in the summer at which time they are either unpalatable or recovering after spawning and of poor quality or 'lean'. A legally-enforced closed season on the sale of Flat Oysters in the United Kingdom covers the period 15 May to 4 August. Portuguese and Pacific Oysters are not included as they rarely breed in British waters and are in season all year round. Exploitation of a summer market for these oysters has been restricted to coastal resorts and its expansion hampered by a general ignorance of this distinction between oyster types.

8.3 OYSTER QUALITY

Oysters are eaten live in the half-shell and the importance of quality control is well appreciated. Oysters are cleaned and sorted by the producer into grades prior to sale. Grading is on the basis of size, weight and shell appearance and relies heavily on the producers' experience and knowledge. Native Flat Oysters are marketed between 45 - 100 grammes with greatest demand for large (9 - 10 cm across the shell), deeply-cupped oysters. Portuguese and Pacific Oysters market at an average size of 60 - 70 grammes and are only sorted into two or three grades. Very large oysters of any species are too big for the half-shell trade and do not have a ready market. Cole (1956) outlined six factors which are taken into consideration when grading *O. edulis* but they are equally applicable to all types of oyster:

> Size; Depth of shell or 'heel'; Size of meat; Plumpness of meat; Colour of meat; Freedom from blemishes on the inside and outside of the shell.

Pacific oysters are particularly prone to form shells composed of convoluted layers of conchliolin which make the shell both unsightly and easily abraded. When grown in trays distorted shells are common if regular thinning out is not performed. Both these factors tend to downgrade the appearance of the shell and, therefore, the oyster.

Appearance, taste and presentation are of paramount importance for oysters. Few people consider the nutritive value of oysters although they are a good source of many essential dietary items (Murray and Burt, 1969). It is claimed that connoisseurs can identify the origin of a Native Flat Oyster from its appearance and taste. The importance of flavour, colour and texture reaches its zenith in France where *O. edulis* are grown in claires for a period to achieve the greenish colouration characteristic of the 'huitre verte'.

The appearance and slightly different flavour of Portuguese and Pacific Oysters are important reasons why these oysters are not held in the same esteem as *O. edulis*.

The ideal oyster for consumption in the half-shell is a large, regular shaped, deeply-cupped oyster with the shell clean and white inside and well-filled with plump, white meat.

8. THE STATUS OF OYSTER PRODUCTION IN THE UNITED KINGDOM AND EUROPE

The United States is the world's largest producer and market for oysters with Japan and the Republic of Korea as the most important exporting countries. Approximately two-thirds of the world trade is in fresh or frozen oysters and the remainder are canned and a small quantity cured. In Europe virtually the entire catch of oysters is marketed fresh in the half-shell. France is by far the largest producer with a nominal catch of 105,919 metric tonnes in 1979. Up until the outbreak of Aber Disease in the last decade France was a major exporter of oysters importing only seed and adult brood stock.

The United Kingdom with a recorded production of 680 metric tonnes in 1979 is ranked fifteenth in world production (Table 3.1). Although production is small in world terms it has been very significant in terms of European production over recent years.

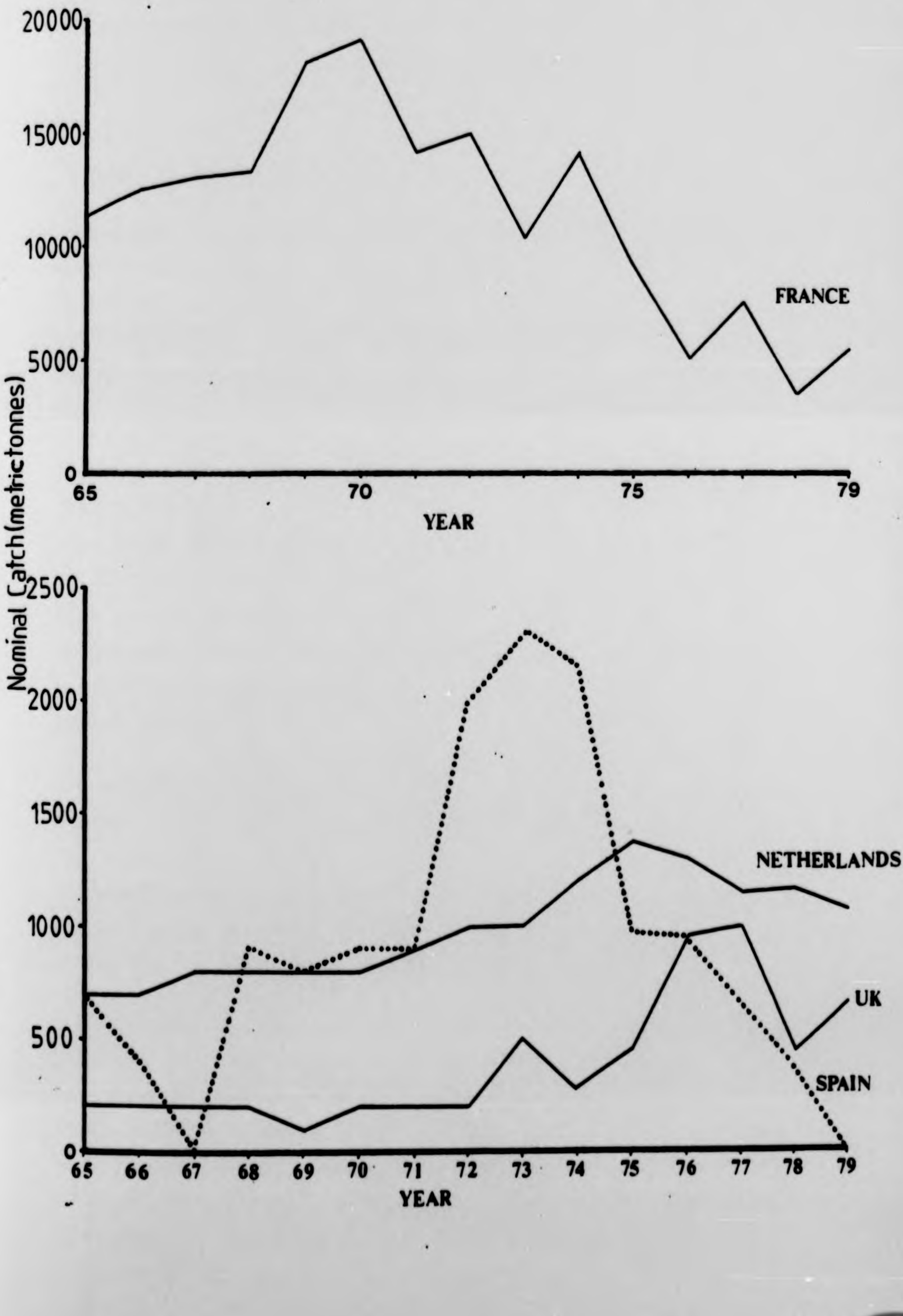
The epidemic known as Aber Disease occurred in the early 1970s and its effects were particularly devastating on the Atlantic coast of Europe where much of the French oyster production is centred. Nominal catches of *O. edulis* for the principle European producers are shown in Figure 8.1 for the period 1965 - 1979. In France production of *O. edulis* plummeted from a peak of 19,100 tonnes in 1970 to 5,504 tonnes in 1979. Landings in Spain are no longer recordable and the Netherlands has also suffered a slight decline in catches. There are some indications that a recovery in stocks is now occurring and that in France production of *C. gigas* has increased to compensate partially for the decline. However, there exists a well-established market for high quality *O. edulis* on the Continent which will not be satisfied by indigenous production for the foreseeable future.

Oyster fishermen in the United Kingdom and to a lesser extent Eire have benefitted from the situation on the Continent. Both countries have been unaffected by Aber Disease and have been able to increase their catch by the exploitation of virgin oyster grounds.

In the South of England the discovery of substantial natural oyster populations in the Solent is the main reason for the upturn in landings evident in Figure 8.1. The official statistics, however, substantially underestimate the true position regarding the size of the oyster industry in the United Kingdom. This situation has been brought about by a number of factors.

There is at present no legal obligation for the fishermen to supply the MAFF with catch data. The official catch statistics do not include most of the oysters sold for relaying either at home or abroad nor do they consider cultivated oysters. The oyster fishing season takes place during the winter months and

Figure 8.1 Nominal catches of *Ostrea edulis* in Europe



the official statistical returns are compiled for the calendar year and thus covers parts of two seasons. The consequences of such a situation is evident in Tables 1.1 and 8.1 which show that in 1979 the recorded nominal catch of oysters was 680 tonnes yet the Customes and Excise Returns show that United Kingdom exports of oysters alone totalled 1,117 tonnes.

8.4.1 United Kingdom Oyster Exports

Throughout the period considered in Table 8.1 the United Kingdom has become an increasingly important exporter of oysters. This trade has been primarily with Europe but the number of countries of destination is far greater and more widespread throughout the world than the nations from which Britain imports oysters.

Exports of small *O. edulis* which include both natural and hatchery production are almost exclusively to the Continent, mainly France and to a lesser extent the Low Countries. The decline of the French and Dutch oyster industries, the success of British hatcheries and the development of the Solent fishery have all contributed to the growth of this trade (Table 8.2). At present approximately 90% of the production of British hatcheries is exported before it has grown to consumable size (Anon, 1980a).

The export of mature oysters has shown a similar expansion in recent years. Exports of *C. gigas* (recorded in the Returns as *O. virginica*) are of a low level and destined mainly for the Continent where there is an established market. In Britain, *Crassostrea* is generally regarded as a poor substitute for *O. edulis*, an attitude which does not prevail in Europe.

The majority of 'Other Oysters in the Shell' exported are adult *O. edulis* but the figures do include spat and mature *C. gigas* . The sales of oysters to the Rest of the World is composed of small quantities sent to many different countries. The diversity of this trade category may be a reflection of the status of the British grown *O. edulis* as a luxury food item. The recent rise in exports to the affluent Middle East lends some credance to this suggestion.

Table 8.1 United Kingdom Exports of Oysters by Quantity (metric tonnes) and Value (£) to all importing countries (1974 - 1979)

Importing Country		1974	1975	1976	1977	1978	1979
France	tonnes	126.59	273.81	468.55	539.56	606.06	619.34
	£	76,343	191,341	406,975	553,829	771,095	966,026
Netherlands	tonnes	0.0	17.78	77.21	39.47	174.48	355.09
	£	0.0	17,105	84,905	67,641	347,929	683,328
Spain	tonnes	18.49	7.06	82.07	33.91	0.0	49.43
	£	17,874	3,760	55,132	18,488	0.0	133,121
Belgium/ Luxembourg	tonnes	12.24	49.58	43.70	44.23	45.64	40.19
	£	10,002	37,635	50,515	57,130	143,661	95,880
Federal Republic of Germany	tonnes	19.00	20.57	34.39	41.82	33.85	28.19
	£	15,266	20,388	46,365	64,073	67,814	76,480
Eire	tonnes	5.23	0.41	1.71	4.33	2.08	4.02
	£	4,235	3,052	6,851	15,148	28,393	43,133
Other European	tonnes	9.30	1.37	0.04	0.57	0.72	2.81
	£	4,760	1,827	550	802	3,050	4,061
Middle East	tonnes	0.0	0.15	1.22	2.13	1.53	16.26
	£	0.0	445	1,733	4,133	4,377	9,870
Rest of the World	tonnes	0.05	11.48	3.11	0.0	0.03	1.73
	£	471	6,687	4,720	0.0	1,654	15,903
TOTALS	tonnes	190.90	382.20	712.00	706.02	864.39	1,117.06
	£	128,951	282,240	657,746	781,244	1,367,973	2,007,802

Table 8.2 United Kingdom Returns of Export of Oysters by Type of Oyster, Quantity (Kgs) and Value (£) for the period 1974 - 1979

Type of Oyster		1974	1975	1976	1977	1978	1979
O. edulis not more than 40g each	Kg	149,758	277,063	303,007	189,446	320,722	360,131
	£	77,294	186,963	287,687	212,226	408,158	613,125
C. angulata in the shell	Kg	22,606	29,769	93,639			
	£	39,012	13,822	80,459			
					Kg 516,581*	542,659*	756,944*
					£ 569,018*	959,815*	1,394,677*
Other Oysters in the shell	Kg	17,933	74,676	315,325			
	£	12,495	80,848	289,300			
Other than *O. edulis* not in the shell	Kg	610	711	12			
	£	150	607	300			
TOTALS	Kg	190,907	382,219	711,983	706,027	864,381	1,117,075
	£	128,951	282,240	657,746	781,244	1,367,973	2,007,802

Notes:

1. Oysters merely in transit through the United Kingdom are excluded.
2. All statistics include the trade of the Channel Islands and the Continental Shelf (UK part).
3. * Denotes that after 1976 all trade other than *O. edulis* NMT 40g each is grouped together as 'Other Oysters'.
4. *Crassostrea angulata* are recorded in the Returns as *O. virginica* (American Oyster). This is almost certainly an error.

Source: HM Customs and Excise Statistical Office.

It can be seen from Table 8.2 that few shucked oysters (oyster meat removed from the shell) are exported. Processing of oysters except on an experimental basis is virtually unknown in the United Kingdom. In Britain and Europe as a whole oysters for human consumption are preferred fresh in the shell, great importance being placed upon the quality of the meat and shell. Since Europe forms the main export market for oysters it is to be expected that shucked oysters and oyster products will not form a significant export.

8.4.2 United Kingdom Oyster Imports

Oyster imports into the United Kingdom are divisible into two categories: small *O. edulis* which are relaid on British oyster beds to be grown and fattened to a size suitable for the home market; and mature oysters imported for direct human consumption. For data prior to 1976 it is possible to further divide this latter category to show shucked and other species in the shell (Table 8.4).

Oysters for relaying are imported principally from Eire though up until 1977 oysters were imported from Norway each Spring (Table 8.3). All imports of seed oysters from France have been banned because of the disease problem and are likely to remain so. The West Country oyster grounds were very dependent on these oysters and the decline of these fisheries in the 1970s was due to a shortage of seed oysters. Alternative sources of oysters have now solved this problem. Overall the importance of this area of oyster trade has declined due to the increase in home grown *O. edulis* seed and tighter import controls on shellfish.

The main supplier of adult oysters has again been Eire. Its proximity to Britain and large stocks of 'clean' oysters both contributing to the importance of the Irish fisheries. Quantities of mature *C. angulata* in the shell are imported from France and Portugal. Traditionally this trade is greatest when supplies of home grown *O. edulis* are low; in the summer or during a bad season. However, both countries have suffered the

Table 8.3 United Kingdom Imports of Oysters by Quantity (metric tonnes) and Value (£) from all countries of origin (1974 - 1979)

Country of Origin		1974	1975	1976	1977	1978	1979
Eire	tonnes	6.35	10.47	40.12	94.92	102.85	85.33
	£	6,643	10,179	50,645	126,124	199,897	184,362
Japan	tonnes	19.91	1.83	1.81	2.21	21.95	45.95
	£	30,838	2,080	2,915	4,290	43,752	69,449
Australia	tonnes	21.29	0.0	9.77	1.91	3.75	7.96
	£	26,427	0.0	22,483	5,288	11,146	20,089
Portugal	tonnes	14.99	14.99	12.00	0.0	0.0	0.0
	£	3,268	4,449	4,560	0.0	0.0	0.0
France	tonnes	0.05	0.0	3.47	2.30	4.89	9.93
	£	105	0.0	8,634	4,798	9,586	18,108
Norway	tonnes	1.37	4.67	6.24	4.17	0.0	0.0
	£	684	4,864	10,583	8,611	0.0	0.0
Canada	tonnes	0.0	8.33	0.0	3.67	0.0	0.0
	£	0.0	12,472	0.0	6,358	0.0	0.0
Others	tonnes	4.93	0.56	0.31	2.06	2.88	5.76
	£	3,282	2,036	3,345	2,375	5,969	7,064
TOTALS	tonnes	68.89	40.85	73.72	111.26	136.32	154.93
	£	71,247	36,080	103,165	157,844	270,350	299,072

Table 8.4 <u>United Kingdom Returns of Imports of Oysters by Type of Oyster, Quantity (Kgs) and Value (£) for the period 1974 - 1979</u>

Type of Oyster		1974	1975	1976	1977	1978	1979
O. edulis not more than 40g each	Kg £	1,829 1,164	11,227 11,979	28,399 40,111	29,675 41,300	8,952 15,685	9,683 16,403
C. angulata in the shell	Kg £	22,403 10,356	16,815 5,801	20,457 26,107			
					Kg 81,579* £ 116,544*	127,372* 254,665*	145,244* 282,669*
Other Oysters	Kg £	13,106 18,718	2,082 1,712	21,824 27,147			
Other than *O. edulis* not in the shell	Kg £	31,547 41,009	10,719 16,588	3,047 9,800			
TOTALS	Kg £	68,885 71,247	40,843 36,080	73,727 103,165	111,254 157,844	136,324 270,350	154,927 299,072

<u>Notes:</u> as Table 8.2

effects of oyster disease and exports to Britain have declined. Some recovery of their oyster stocks has occurred but both are likely to remain net importers from the United Kingdom for the immediate future.

Japan, Australia and Canada account for the bulk of the imported shucked oysters and Other Species. It is not possible from the Customs and Excise Returns to determine the exact degree of processing these shucked oysters have undergone but it is common practice in each of these countries to market oysters in sophisticated products.

At present imports of oysters and oyster products to the United Kingdom derive from very few countries and this trade is small compared to the volume of exports.

8.4.3 United Kingdom Home Market

Historically the difference between the United Kingdom production level and net exports provided a measure of the size of the home market for oysters. Prior to the expansion of the European export market this figure was in the region of 150 metric tonnes per year. The recent increase in production has gone primarily to the Continent rather than to expand the home market. In addition to captured oysters it is estimated that the sale of mature, cultured *C. gigas* for human consumption is in the region of 250,000 per annum (Anon, 1979a).

Based on these estimates the total home market for oysters at present would appear to be no more than 200 - 250 tonnes per annum with a first sale value in the region of £250,000. This is small compared to the net export trade which realised nearly £2 million in 1979. These figures would indicate a total production in 1979 in the region of 1,300 tonnes double the official nominal catch of oysters.

A final point must be made with regard to the present market for oysters. The exploitation of an export market on the Continent has brought considerable benefit to the fisheries on the South coast of England. However, the long term consequences of such a policy may not be fully appreciated. Oysters have been diverted from the home market which has not been developed to the extent to which might have been expected given the upturn in catches over the last few years. Oyster grounds on the Continent are already showing signs of a recovery and eventually British oyster producers may be forced to return to a neglected home market. More effort must be expended to realise the considerable potential market for oysters in Britain.

8.5 OYSTER DEMAND ANALYSIS

The consumption of shellfish in Britain is stable at a very low level and is only marginally recordable. A comparison of household consumption and expenditure on shellfish and broiler chicken will serve to put the dietary contribution of shellfish into perspective.

Table 8.5

ITEM	National Average Consumption grammes/person/week	National Average Expenditure pence/person/week
Shellfish	2.27	0.98
Broiler chicken	121.91	15.16

Source: MAFF (1980)

Oysters form a small proportion of the total shellfish consumption and expenditure and it is not possible to collect data upon which to base a demand curve for oysters. However, nephrops, lobsters and oysters are all grouped at the top of the shellfish price range, and together constitute over 60% of the total value of shellfish landed. It would seem reasonable to assume that the measures of the responsiveness of demand for oysters to changes in price or income (price and income elasticities of demand respectively) concur with the values shown in Table 8.6 for shellfish.

Table 8.6 Estimates of Elasticities of Demand for Fish and Shellfish in 1979

(a) Income Elasticities of Demand in 1979

ITEM	Income Elasticity of Expenditure	Income Elasticity of Quantity Purchased
Shellfish	1.14 (0.55)*	1.06 (0.68)
All Fish	0.25 (0.05)	0.15 (0.06)

(b) Price Elasticity of Demand

ITEM	Own Price Elasticity of Demand	Period Estimate Covers
Shellfish	-0.52 (0.27)	1974 - 1979
All Fish	-1.13 (0.26)	1972 - 1979

* Figure in brackets is standard error of estimate.

Source: MAFF (ibid).

These latest official figures indicate that the Income Elasticity of Demand for shellfish is positive and far more responsive to changes in income than fish in general. Hence as disposable income increases the individual can be expected to spend proportionately more money on shellfish. Estimates of the Price Elasticity of Demand show it to be inelastic and thus demand for shellfish is less sensitive to increases in price than fish as a whole.

The statistics indicate that the demand for shellfish is small but it has been suggested previously that the market is under-developed at present. Given the opportunity individuals will increase their purchases or maintain their level of purchases if prices rise. These points are consistent with the view of shell-fish and oysters in particular as a luxury food item.

Geographically oyster consumption is highest in the south east of England and demand greatest in the upper socio-economic groups. Apart from such generalisations the small size of the market and the dearth of data do not permit or at present justify any detailed demand analysis for Britain.

Studies carried out on the demand for oysters in the United States are conflicting. Marasco (1974) concluded that demand for sea food in the USA was inelastic with respect to price and income. Specific oyster studies have produced estimates of price elasticity of demand which range from negative, inelastic (Millar and Nash, 1974) to elastic and positively related to real income (Agnello and Donnelly, 1975; Johnston and Nelson-Swartz, 1976). The differences between the American and British markets for oysters appear to be sufficient to render direct comparison of demand analysis results invalid.

8.6 STRUCTURE OF THE INDUSTRY

The development of hatchery rearing techniques by the MAFF freed the industry from its dependence on natural spatfalls and made oyster cultivation feasible. Currently there are five main hatcheries and nurseries operating in the United Kingdom. The largest is Seasalter Shellfish Limited which produced over 90 million seed oysters in 1979 (Anon, 1979a). Hatchery production is now reliable and continuity of supply of high quality spat and seed oysters is ensured.

The commercial cultivation of Pacific Oysters in Britain is still very much in the embryonic stage. Lack of expertise in growing techniques, under capitalisation and an uncertain market have all contributed to its slow development. The distribution of suitable sites has produced a fragmented on-growing sector with virtually all enterprises being privately owned and operated by one or two individuals. The total stock of *C. gigas* under cultivation in Great Britain is estimated at 4 - 5 million oysters (Table 8.7). Sales of cultivated oysters for human consumption are much lower. In Scotland there are presently twelve mollusc farms with a combined output of 200 tonnes of mussels, oysters and scallops. By the first half of 1981 producers are expected to have 167,000 oysters for sale and output is due to reach 380,000 by the end of 1981 (Anon, 1981). In Wales, Mona Seafoods of Anglesey are reported to have wholesaled 100,000 mature *C. gigas* in 1979 principally to coastal resorts in the North West of England (Davies, 1979). Estimates suggest that as much as 80% of cultivated oysters are retailed through local hotels, restaurants and sea food stalls.

Some ongrowers have attempted to develop inland markets. Oysters from the West coast of Scotland find their way to outlets in Central Scotland and Devon oysters are delivered weekly to the Midlands by one ongrower. Such efforts require the ongrower to spend at least one day per week on marketing so it is essential to maintain a reasonable volume of regular sales. A weekly sales target of 1,000 oysters is considered economic by some growers but because of the small scale of their operations at present they are often dependent upon buying stock from other growers to maintain their market share.

By contrast most oyster fisheries are worked by limited companies or local fishermen, and all fishing is concentrated in the South of England (Davidson, ibid). The Helford Oyster beds are operated by MacFisheries Ltd on behalf of the Duchy of Cornwall. Bentley's Restaurant in London own oyster beds in West Mersea, Essex, from which they supply other as well as their own needs. Over the long history of this sector of the industry regular market channels and an elaborate system of grading have evolved. Supplies go mainly to the 'upmarket' restaurant trade with approximately 50% going direct for retail and the remainder being sold through wholesalers. More recently a high proportion of oysters from the Solent fishery have been exported.

Table 8.7 Estimated stock of *C. gigas* under cultivation held by ongrowers for the period 1977 - 1980

Region	1977	1978	1979	1980
England and Wales	1,170,000	3,000,000	2,700,000[a]	3,000,000
Scotland	300,000	300,000	450,000	780,000
Ireland[b]	570,000	1,000,000	750,000[c]	1,150,000
Channel Islands[d]	0	0	750,000	500,000[e]
UK TOTAL	2,040,000	4,300,000	4,650,000	5,430,000

Notes:

a. One company pulled out (minus 250,000 *C. gigas*).

b. Includes both Eire and Northern Ireland.

c. Drop due to companies leaving the business.

d. Guernsey and Jersey.

e. Company now only deals with *O. edulis* (minus 250,000 *C. gigas*).

Source: Survey conducted by the Shellfish Association of Great Britain.

8.7 DELIVERY

It is normal practice throughout the industry for the producer to supply his own market direct. The cost of this is incurred by the producer but more important for the ongrower is the time required for distribution and market development. The main benefit to the oystermen is the large degree of control this gives them over supply. Independence of transport concerns helps minimise the risk of oysters deteriorating during delivery, especially in warm weather.

Oysters are sent to retailers in response to pre-arranged orders or contracts. Prior to delivery they will be held on the foreshore or in oyster storage pits. Retail outlets buy in oysters as demand dictates and do not usually hold them for any length of time.

The traditional method of carriage is wooden barrels but nowadays these are expensive and difficult to procure. Sacks or old boxes are the most commonly used containers. Oysters will travel well in these and survive out of water for several days if tightly packed with the deeper, cupped shell valve downwards.

There are no special regulations or restrictions on the carriage of oysters by rail, road or sea and neither refrigeration nor other special facilities are necessary since the bulk of the trade occurs in winter.

8.8 OYSTER PRICES

8.8.1 Oyster Spat

Hatcheries produce spat and seed oysters in the size range 0.01 - 5.0 grammes. Small quantities of the clam, *Venerupis decussata*, are also produced by some and sold at prices similar to those for *C. gigas*. Prices are ex-hatchery and normally quoted for the hatchery season, October to June though prices differ between hatcheries (Figure 8.1). Discounts of 5 - 10%

are common on large orders over 250,000 spat or for orders placed a few months prior to the delivery date. Delivery is normally charged extra at cost.

The cost of production for very small spat is similar for all species and is reflected in similar prices. However, for larger spat the faster growing *C. gigas* is less expensive to produce and the price curves for the two species start to diverge. Compared to the previous season prices have risen by 10%, in line with price rises in general.

8.8.2 Prices direct from oyster producers

Most ongrowers sell their oysters direct to retail outlets and the price they obtain varies in accordance with local demand and supply conditions. To cover their costs cultivators must receive a premium price and typical prices for 1979 - 1980 season are £15/100 for large *C. gigas* (75 grammes plus) and £10 - £12/100 for medium grades (50 - 75 grammes).

The Colchester Oyster Fishery Limited of Essex is the largest single supplier of *O. edulis* and their 1979 price list quotes from Grade 5's at £13/100 up to Grade 5/0 (approximately 150 g each) at £35/100. The Company also produces the famous 'Pye-fleet' Flat Oyster which is reared in the River Colne and fattened in the renowned Pyefleet Channel. This oyster, regarded by many as the best in the world, sells at prices 10% above those of other Colchester oysters.

The only active oyster fishery in Scotland is in Loch Ryan which this year has produced small quantities of 'Rock Oysters' (*C. angulata*) which sell at prices comparable to those quoted for *C. gigas*.

8.8.3 Wholesale prices for *O. edulis*

Pacific oysters are sold in relatively small lots of a few hundred oysters so the wholesale trade in home grown oysters is restricted to *O. edulis*. Oysters are usually supplied to are common on large orders over 250,000 spat or for orders placed a few months prior to the delivery date. Delivery is normally charged extra at cost.

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Pacific oysters are sold in relatively small lots of a few hundred oysters so the wholesale trade in home grown oysters is restricted to *O. edulis*. Oysters are usually supplied to merchants in sacks of approximately 35 kilogrammes weight. The price the oysters fetch depends on their grade but is strongly influenced by their origin and the demand on the Continent. During 1976 there was a steep rise in the price French buyers were prepared to pay for one year old oysters from £350/tonne in early 1976 to £1,000/tonne at the start of the 1976/1977 season. The wholesale merchants were forced to increase the price of *O. edulis* for human consumption in order to maintain supplies and the price rise between the 1975/1976 and 1976/1979 seasons was much larger than previously (Table 8.8). The high price of Native Flat Oysters was a stimulus to fishing activity and landings increased sharply at this time (Figure 8.1). More recently prices have settled. At the start of the 1979/1980 season Solent oysters were selling at £1,100/tonne rising to £1,200/tonne by February 1980. Essex oysters are regarded as better quality than Solent oysters and this is reflected in a price normally £100/tonne higher. Colchester oysters currently fetch £1,300/tonne for mixed grades.

Wholesale fish markets handle oysters, by far the main outlet being Billingsgate in London which is discussed in Section 8.9. At present such markets handle mainly *O. edulis* which are sold in five grades known as 'ones', 'twos', 'threes' etc. Prices are quoted at the start of each season by the wholesalers and prices for the 1979/1980 season range from £17/100 for Grade 5 or 'buttons' up to £32/100 for Grade 1. Prices vary between markets, for example they are lower at Manchester Wholesale Market each grade selling at a price quoted for one grade smaller in London. The provincial markets by comparison to Billingsgate handle very few oysters. Manchester handles less than 1,000 oysters per week during the main oyster season. Wholesale prices have risen approximately 15% per annum during the 1970s and reflect an average mark-up between producer and wholesaler of just over 30%. It is possible to show that the wholesale price of oysters have risen more than average price by comparing them with a price index. The index used in Table 8.9 is Catering Expenditure on Food. This is an index generally based on wholesale food prices for expenditure by commercial and non-commercial catering establishments and is

Table 8.8 Wholesale Prices for Oysters (*O. edulis*) quoted by Merchants at Billingsgate Market for the period 1973 - 1980

Season	Wholesale Price (£/100 oysters)					
	Grade					Average Price
	1	2	3	4	5	
1973/1974	12.80	10.60	8.20	6.60	5.20	8.68
1974/1975	14.60	12.10	9.50	7.50	6.00	9.94
1975/1976	17.60	14.60	11.60	9.20	7.20	12.04
1976/1977	22.00	18.00	16.00	13.00	11.00	16.00
1977/1978	25.00	21.00	18.60	15.00	13.00	18.52
1978/1979	28.00	24.00	21.00	17.00	15.00	21.00
1979/1980	32.00	28.00	25.00	20.00	17.00	24.40

Notes:

1. Prices quoted annually by the wholesale merchants at the beginning of the season (September).

2. Billingsgate handles all grades but mainly large oysters (Grades 1 - 3).

3. Approximate sizes for each grade of *O. edulis* are:

Grade 1	80+ grammes
Grade 2	70 - 80 g
Grade 3	60 - 70 g
Grade 4	50 - 60 g
Grade 5	40 - 50 g plus oysters downgraded because of deformed shells ('buttons').

Grades based on Colchester Oysters Company figures.

applicable for comparison with oyster wholesale prices. A simple unweighted index of average wholesale prices has been derived with 1975 as the base year.

Table 8.9 Indices of Wholesale Prices (1975 = 100)

	1975	1976	1977	1978	1979
Catering Expenditure Index	100	119.1	135.0	148.6	171.3
Average Oyster Price Index	100	128.4	157.7	181.0	208.0

Although this is a very crude comparison it serves to show how the relative price of *O. edulis* has increased. There is insufficient data to include the price of *C. gigas*. Information from the Fishmongers' Company suggests that wholesalers are having to offer the producer a high price in order to compete with the demand on the Continent. The wholesaler passes on this increase to his customers.

8.8.4 Retail prices

There is little doubt that at the retail level Native Flat Oysters are regarded as a luxury item and their price in fish restaurants reflects this. In London the Wheeler's restaurant chain who specialise in fish and shellfish currently sell Grade 1 oysters at £4.60 per half dozen and Grade 2 at £4.00 per half dozen, prices which appear typical of the Capital.

By comparison *C. gigas* tend to be regarded as more 'down market' and their prices are lower, depending on location, local supply and the type of outlet. Prices are in the region of £1.20 - £1.80 per half dozen.

For both species the mark-up between retailer and consumer is greatest, a figure of 100% is normal. Such high mark-ups are common where food is prepared but for the oyster half-shell trade preparation is minimal. The profit element can be justified on the basis of the low volume of oyster sales.

8.9 BILLINGSGATE WHOLESALE FISH MARKET

Billingsgate Market is sited in the centre of London and is the largest market in Britain devoted exclusively to the sale of fish. In recent years the market has handled 40% of the domestic trade in *O. edulis* and is by far the largest single outlet for oysters. It acts as both a clearing house regulating supply from several fisheries and also provides the small operator with a permanent outlet for his shellfish. Individual shellfish merchants do not keep extensive records for oysters but it is possible to gain an insight into the working of the Market from the records of the Worshipful Company of Fishmongers' who monitor and maintain the quality of fish in the market through their role as Fish Inspectors.

The main oyster fisheries in Britain fall into three geographical regions: The South west of England, the Solent area and Essex and Kent. Other oysters occasionally arrive at Billingsgate from Scotland, Ireland and France, the latter supplying Portuguese oysters. Monthly arrivals of oysters at the Market by region are summarised in Table 8.10.

Both the South west and South east fisheries have declined in importance in the Market whilst since its initial commercial exploitation in the early 1970s the Solent area has risen to be the most important fishery. The ban on the import of French oyster spat has been a factor in the decline of some fisheries. Supplies from other fisheries tend to be irregular and do not form a significant part of the total arrivals although French oysters imported during the summer months serve to keep the oyster presence in the market throughout the year.

Within each of the three regions one fishery accounts for over 80% of the Billingsgate arrivals: the River Helford in Cornwall, West Mersea in Essex and Poole in the Solent. Supplies from these regions tend to peak at different times. Essex arrivals are greatest at the start of the season whereas Cornwall stock will not reach peak condition until October at least. It has been suggested that in the deeper, cooler waters of the South west spawning continues late into the summer so that Cornwall oysters have not fully recovered by the start of the season

Table 8.10 Monthly Arrivals of Oysters (metric tonnes) at Billingsgate Wholesale Market over the period January 1973 to December 1979 from Oyster Fisheries

YEAR	FISHERY REGION					TOTAL
	Cornwall and Devon	Solent Areas	Essex and Kent	Irish and Scottish	French*	
1973	58.66	42.82	64.12	2.54	0.254	168.39
1974	48.84	39.00	53.645	2.79	0.864	145.14
1975	25.75	85.19	54.42	0.00	0.000	165.36
1976	22.64	61.15	83.48	0.00	0.000	167.27
1977	9.20	98.98	74.40	1.37	0.203	184.15
1978	16.11	43.43	34.36	3.51	0.000	97.42
1979	9.51	28.97	27.80	0.25	3.05	69.58
TOTALS	190.71	399.54	392.23	10.46	4.37	997.31

* *Crassostrea angulata*

Key to English Oyster Regions:

Cornwall and Devon	Solent Area	Essex and Kent
River Helford	Poole	West Mersea
Falmouth	Newtown (IOW)	Rivers Crouch and Roach
River Yealm	Emsworth	River Blackwater
Kingsbridge		Hornsey Island
		Whitstable
		Pyefleet
		Walton
		Brighlingsea

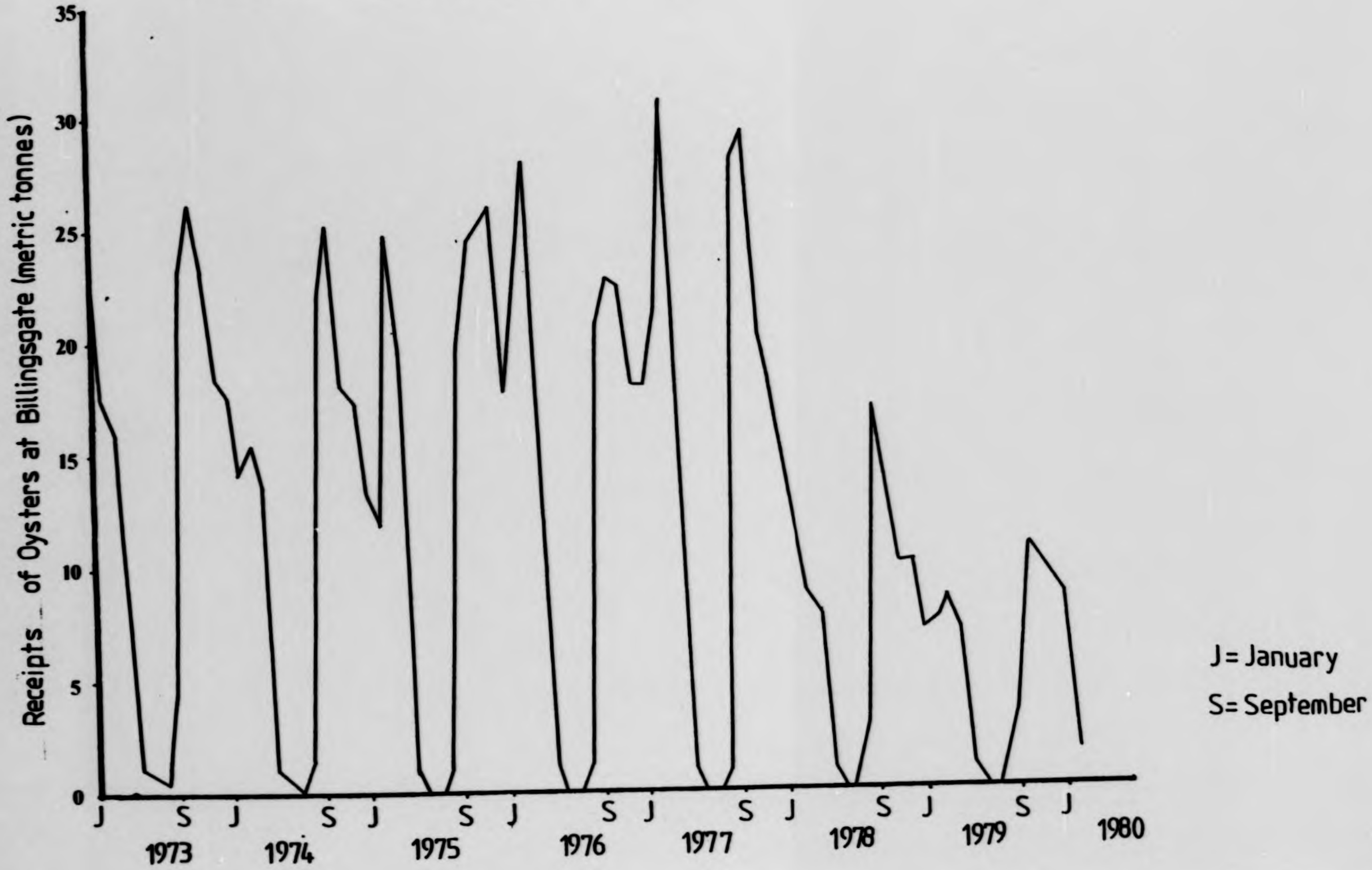
(Cole, ibid). The significance of this to the Market is that supply is more evenly spread over the first half of the season. In general the larger grade oysters come from the Solent and East Coast regions and the medium grades from the West Country areas.

The usual pattern of oyster landings is for a peak at the start of the season then as winter conditions worsen fishing is suspended, resuming after the storms in early Spring. The Billingsgate arrival figures in Figure 8.2 clearly show this distribution of landings up to 1976. After this date there is a marked decline in arrivals and these are restricted to the first half of the fishing season.

Depletion of oyster stocks is certainly not the cause of this fall since the considerable new stocks discovered in the Solent are far from being overfished (Key, 1977a). This trend represents a move away from Billingsgate Market as a major wholesale outlet for oysters. The bulk of the Solent catch is exported direct to the Continent. Spain will only buy oysters for relaying in the Spring and the Dutch market starts in mid February. Together with the French market this explains why Billingsgate Market arrivals have fallen and why the latter part of the season has been particularly hard hit. Billingsgate Market is now closed on a Monday and this restriction has undoubtedly deterred some producers. The Market has not been as successful as European buyers and is declining.

Oyster arrivals are known as 'packages' and are supplied by oyster number rather than tonnage. Oysters are graded at their source and although Billingsgate accepts all five grades demand is greatest for large oysters and these form the bulk of the trade. Deliveries to the Market occur daily but the number delivered may fluctuate widely. Oysters are sold on the day of delivery but some are held overnight if they arrive too late for the day's market or if a bacteriological analysis is requested. Producers will often delay dispatch at the start of the season until late September or October if it has been a late summer in order to give the oysters time to recover after spawning and to reduce the risk of loss during transportation. Once regular deliveries have commenced the quality of oysters from a particular fishery changes little during a season.

Figure 8.2 **Monthly receipts of oysters at Billingsgate Market: January 1973 - February 1980**



Oysters are only a small aspect of the trade carried out at the Market and it is concentrated in the hands of a few specialised wholesale merchants. By far the most important of these is Baxter and Son (a subsidiary of MacFisheries (Wholesale) Ltd). Since their takeover of the Seasalter and Ham Oyster Company in 1976 this company has had a virtual monopoly over oyster transactions at the Market (Table 8.11). Other merchants occasionally handle *O. edulis* or as in the case of Bloomfields have specialised in exotic shellfish and handle French and very occasionally small quantities of Pacific Oysters.

Prices are fixed at the start of the season by the wholesaler to compete with the price offered to the producer by continental buyers. In the absence of competition between the wholesalers the Market has become increasingly dependent on its traditional links and trade built up over many years. For example the importance of the Essex fisheries was in part due to their proximity to the Capital.

Wholesalers at the Market tend to be conservative and concentrate on the Native Flat Oyster, provincial markets even more so. Portuguese Oysters from France have always been imported when British supplies were unable to satisfy demand but to date very few *C. gigas* have been sold. It does not appear that this is an active attempt by wholesalers to keep the markets for the two types of oyster separate. The reason is that to date the supply of *C. gigas* has been sporadic and of a very low level. To justify handling so few oysters the wholesaler must be able to buy in at a very low price. The producer, however, is often operating on a very tight financial budget and needs to receive a premium price in order to stay in business. For this reason large wholesale markets have been virtually closed to oyster ongrowers and are likely to remain so until this sector of the industry can provide a substantial, regular volume of *C. gigas*.

The bulk of oyster sales from Billingsgate go to hotels, restaurants and other retail outlets in Greater London. None at present go for export or for processing. Its importance has declined but the Market is likely to remain the main domestic outlet for mature *O. edulis*. Billingsgate's position within easy delivery distance of the major fisheries and retail outlets gives it a substantial advantage over other wholesale markets.

Table 8.11 **Receipts of Oysters by Wholesale Merchants at Billingsgate Market over the period January 1973 to December 1979 expressed as a percentage of the total year's receipts**

YEAR	WHOLESALE MERCHANT						TOTAL RECEIPTS (metric tonnes)
	Baxter and Son	Seasalter	C H Ashdown	G Tabor	R Bloomfield	Others	
1973	27.23%	59.29%	5.31%	8.17%	-	-	168.39
1974	31.42	59.00	3.40	6.20	-	-	145.14
1975	70.08	26.72	1.63	1.57	-	-	165.36
1976	91.25	6.28	1.74	-	-	0.73	167.27
1977	97.25	-	1.88	-	0.87	-	184.15
1978	92.51	-	3.76	-	3.63	0.10	97.42
1979	84.05	-	2.49	-	6.61	6.85	69.58

8.10 PROCESSING OF OYSTERS

The processing of fish and the development of fish products has been a particularly slow growing area of the food industry. The oyster industry is one which has largely escaped any degree of mechanisation or attempts to develop new oyster products. The European preference for fresh, live oysters and the relatively low level of catches account for this situation.

This is not true of all molluscan shellfish. The harvesting of cockles (*Cardium edule)* and mussels (*Mytilus edulis*) has become mechanical on the larger European fisheries (MAFF, 1973; Westbrook, 1978). The extracted meats of these shellfish are commonly sold bottled, canned or in sachets through various types of retailers (Figure 8.3).

Processing of oysters in the United Kingdom usually extends simply to cleaning the shell of epiphytes and epizootes which are both unsightly and odourous. Purification to reduce bacterial contamination is commonly carried out. Occasionally oysters are shucked and the entire oyster used in soups or other products. Such products form a major outlet for oysters in the United States but are the exception in Britain. Few people are aware that steak, kidney and oyster pie is a traditional English dish.

The shucking of oysters by hand is a dirty, smelly, laborious job which few people are willing to perform. It takes a considerable amount of time to become adept at shucking so that the minimum amount of meat is lost. Wheaton (1971) describes in some detail the shucking process and calculated that it takes the average shucker eight seconds to separate each oyster. The steps in the process are:

(i) Select an oyster and orientate it for shucking.
(ii) Insert the knife between the shell valves.
(iii) Cut the connection between the adductor muscle and each half of the shell.
(iv) Remove the oyster meat from the shell.
(v) Inspect and grade (if necessary) the oyster meat.

Mechanisation of this process is possible and in a later paper he discusses the biological and technical design constraints of such a machine (Wheaton, 1974). In Britain the White Fish Authority (WFA) has developed a prototype machine to operate at a rate of 50 oysters per minute (Denton, pers comm). Processing oysters at source would reduce transportation costs since the oyster meat only forms 11 - 17% of the total weight and all is edible (Waterman, 1964). Shucked meats also have the advantage that they may be frozen in prime condition and used all year round. Quick frozen oyster meats should have a shelf life of six months if kept at -30°C and three months at -18°C making handling and preparation a lot simpler for the retailer (WFA, 1974).

At present the volume of oysters processed in the United Kingdom is negligible and the high capital cost of such machines cannot be justified.

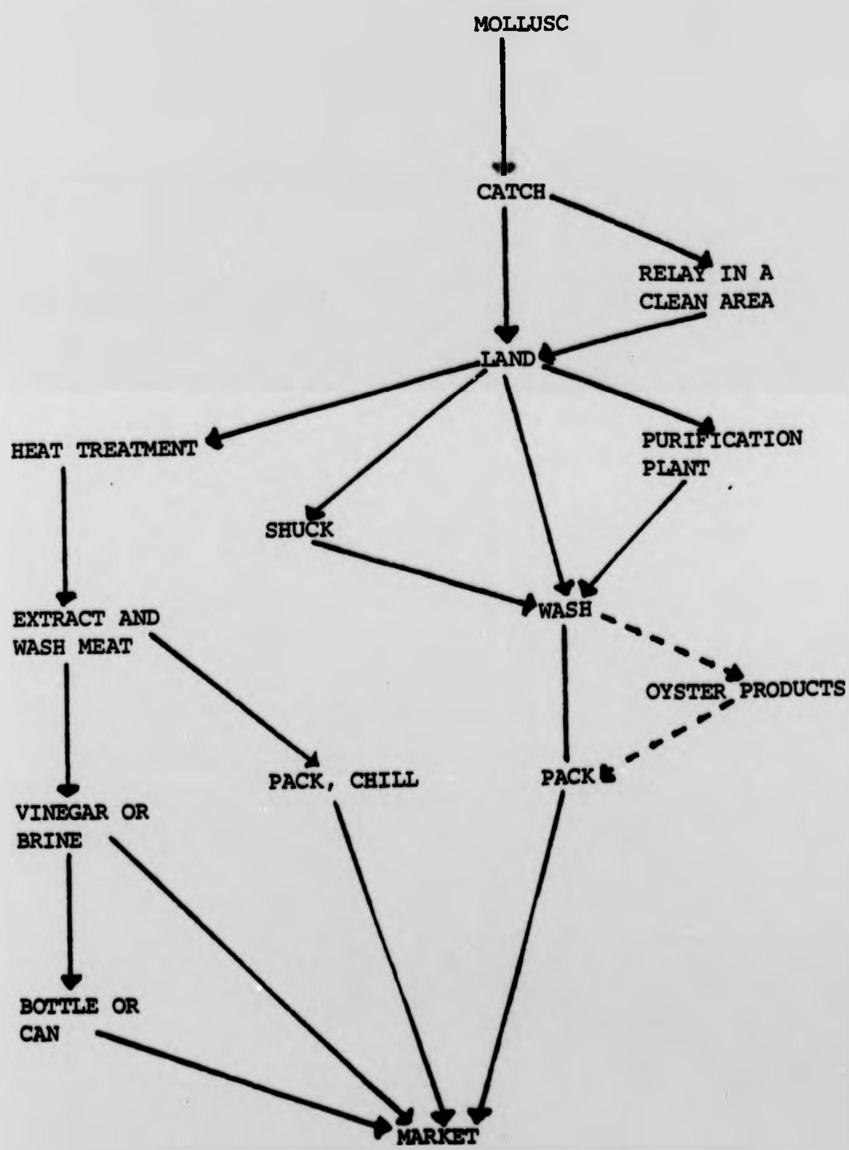
8.11 NEW OYSTER PRODUCTS

In the last decade the WFA Market Development Unit has done a considerable amount of work on the development and market testing of a range of oyster products. The Authority believed that one of the most effective ways of expanding the market for molluscs was to introduce new products which took account of modern market trends and changes in consumer behaviour.

The products were devised with the utilisation of United Kingdom grown *C. gigas* specifically in mind. It was believed that in this way the cultivation of oysters could be encouraged and a market developed which would complement rather than compete with the traditional 'half-shell' trade of *O. edulis*. Products developed included breaded and battered oysters, pies and packs of meat all of which were tested for acceptability to both caterers and potential consumers.

The results of these tests were far from promising. It was concluded that although the British are becoming less conservative in their choice of food and despite increasing trends towards

Figure 8.3 Principle methods of Handling and Processing Molluscan Shellfish



Based on Wood (1976).

'prepared foods' and eating out the consumer was not yet sufficiently adventurous to accept the oyster products that were tested. Even more discouraging was the reluctance of distributors and caterers towards selling the products. Their support was considered crucial to the success of the operation (Urch, 1976).

Caterers generally expressed the view that the cost of the oyster meats would be a major factor in deciding whether they would use oysters. They suggested that the best outlet for the products was direct sales to the housewife through supermarkets. In this way they hoped to popularise the oyster which in turn would lead to increased demand through restaurant sales. Small retail outlets were found to be very conservative and unwilling to push the products. Few food manufacturers showed interest in the WFA costings showing a 30 - 40% margin on the products for the manufacturer and a 25% margin for the distributor.

Consumer attitudes were complicated by several misconceptions concerning oysters. A lack of familiarity with oysters made people unwilling to try the products. First-time eaters were generally deterred by the appearance of oysters in the shell though their attitude was more favourable when the oysters were disguised in breadcrumbs or batter. Confirmed oyster eaters invariably regarded the products as inferior and claimed that processing destroyed the delicate flavour and appearance of fresh oysters, both features of some importance.

Fears concerning the safety of eating shellfish were widely voiced and interviewees believed that only unfresh or inferior quality oysters would be used in products. Few people were aware that *C. gigas* is in season throughout the year.

In general people were unfamiliar with the shellfish because of the scarcity of oysters and their high price. The majority of individuals were ill-informed or ignorant regarding the consumption of oysters. The report concluded that there was no viable commercial market for the oyster products at present.

8.12 FUTURE MARKETING POLICY

Britain has been in the forefront of the technical development of shellfish culture but has paid scant attention to the problems of innovating these developments, nurturing the industry and marketing. The point has been reached where the development of production techniques is completed and from now on the challenge is in the market place. The scattered nature of the industry has led to marketing activities being disorganised and unprofessional. Mollusc production will fall well short of its full potential unless producers start working towards the creation of a fully integrated distribution and marketing structure. The goal of the producer must be to supply a controlled quality of mollusc in a form acceptable to the customer in a regular volume which is sufficient to yield an acceptable return on investment.

The size of the oyster market is only a fraction of what it was a century ago. Its past status is often quoted as a measure of the potential market which exists but such comparisons are invalid. Present market conditions are totally divorced from those prevalent in the oyster's heyday. Modern marketing techniques are unlikely to expand the market to previous levels and development will be spread over several years. It has been suggested that Scotland alone could support a 1,000 tonne per annum farmed mollusc market but such estimates are little more than guess-work. There is a real need for professionally conducted market research to establish the size and nature of the potential market for oysters.

The Native Flat Oyster has a traditional, conservative market where appearance and presentation are important. This oyster has a well established position in the high price sector of the food market. In view of the high price it can command and the ready market there is no reason to change its marketing strategy.

The key to the development of the market for *C. gigas* is continuity of supply. In the past irregular supplies have deterred many potential customers. In the fresh food market where shelflife is very short, availability is an important criterion used by the retailer to select his product range.

A regular supply could be achieved through larger production units, vertical integration or marketing co-operatives. Site requirements and labour costs are constraints on the development of large intertidal units. In some instances vertical integration may be feasible. MacFisheries are able to exert a good deal of control over their supply of oysters as they own oyster beds, a wholesale business and retail outlets. The third approach would bring more immediate benefits and facilitate control and rationalisation of supply and distribution. Co-operative marketing would achieve real rewards through reduced purification, distribution and marketing costs. The initial impetus for such developments must come from the ongrowers. Organisations such as the Shellfish Association of Great Britain and the National Farmers Union have a valuable role to play in helping to organise co-operatives, co-ordinating their activities and dissemination of information. Government agencies are unlikely to provide the lead in commercial aspects of mariculture.

The market for cultivated oysters was expected to develop as a compliment to the half-shell oyster trade of *O. edulis*. Research has centred on processing and oyster products but this approach has failed. Cultivated oysters are primarily sold fresh in the locality. There is no doubt that the supply of cultured oysters has been inadequate for any viable attempt at commercial processing. The WFA product developments were presented too early in the evolution of the industry to be launched commercially. Production levels have increased but processing is unlikely to be attractive as long as ongrowers market their produce individually. Output will continue to centre on the production of a high quality oyster for retail in the half shell. Ongrowers will continue to sell *C. gigas* directly to the retailer. Cultivated oysters will sell in the market sector dominated by *O. edulis* but should find a niche given the underdeveloped nature of this market.

Shellfish farmers must develop a network of outlets for their produce if they are to achieve good progress in the market place. Potential outlets are restaurants, fishmongers and shellfish stalls. Supermarkets are likely to prove a poor outlet for a number of reasons. They are not a good outlet to launch a specialised product since competition for shelfspace is very keen. In general such stores operate on the principle of high turnover, low margin and prefer processed and convenience foods.

The pricing policy for cultivated oysters must be reviewed. For similar sized oysters the price of *C. gigas* is approximately half that for *O. edulis*. This price does not accurately reflect the costs and risks inherent in aquaculture. If the Price Elasticity of Demand is inelastic as suggested it will be possible to increase the price of cultured oysters without significantly affecting demand. It has been demonstrated in Chapter 7 that a 20% increase in the price of 70 gramme *C. gigas* is sufficient to give a positive rate of return in every investment appraisal performed. In monetary terms this is equivalent to a price change of only £2.20/100 oysters. A price increase would considerably enhance the commercial viability of oyster culture yet leave the Pacific Oyster well below the price of comparable *O. edulis*. Any change in pricing policy must be adhered to by all producers and should be co-ordinated by an organisation representing the interests of the producers.

The publicity shellfish receive is invariably bad. The consumption of molluscs is very sensitive to food poisoning 'scares'. Outbreaks of shellfish poisoning are very rare in Britain and almost exclusively associated with the consumption of badly prepared mussels (Ayres and Cullum, 1978). It is important that quality control standards are maintained and that misconceptions regarding molluscs are dispelled. The introduction of legislation to make the purification of oysters prior to sale compulsory and the establishment of a scheme to monitor oyster quality would serve to alay fears regarding shellfish poisoning.

Advertising, when used, has been restricted to trade papers and journals and has been directed at caterers and retailers. There is a need to educate the potential consumer regarding oyster seasons and preparation. The WFA has prepared relevant leaflet-type literature. This or similar information should be available at the point of sale. Any expenditure on this type of advertising would have to be paid for by producers collectively.

In summary it can be said that the marketing of cultured oysters to date has been restricted to the locality of production and organised by the individual producer. If the industry is to realise its full potential there is a need to establish a more professional approach. It has been suggested that co-operation on the marketing of oysters is essential. There is a need to conduct market research to establish the nature of the potential market and to review pricing policy. Oyster products are not envisaged as being viable in the immediate future. Marketing of oysters for the half-shell trade in specialised outlets is considered to be the most important outlet for *C. gigas*. There exists a need to make people more aware of oysters as a food item and to dispel the misconceptions surrounding this shellfish.

Chapter 9

DISCUSSION AND CONCLUSIONS

9.1 THE STUDY IN PERSPECTIVE

Oysters are one of the most intensively studied marine organisms but the bulk of available information deals with pure biology. In this study emphasis is placed on information regarding the commercial production of oysters. It has drawn information from a diverse range of sources and the multidisciplinary approach adapted in this work is one of its main innovations. This approach has made possible the construction of a framework within which the commercial viability of shellfish cultivation may be evaluated.

Models of oyster growth have been derived which give a more accurate representation of oyster performance in the sea than those presented in earlier studies. The modelling approach has been used in a detailed study of the effects of biological and environmental parameters on the economics of cultivation. From a comprehensive set of costs it has been possible to conduct an investment analysis which maps out the various stages of operations and shows the long term financial yields which oyster culture has to offer. It is hoped that such information will be of value both to potential entrants into the industry and to those actively involved in mariculture. The study identifies both strengths and weaknesses in the industry. It shows that bivalve culture can be a viable sector of the food producing industry even on a small scale of operation. Perhaps more importantly for the future it helps to focus attention on areas which have been neglected or not developed at a rate commensurate with a well-balanced industry. The present small size and slow development of commercial production gives an unusual opportunity for commercial and government interests to agree a long term policy based on detailed studies. In this respect multidisciplinary research has a very practical role to play in directing the future development of the industry.

9.2 RESULTS OF THE ANALYSIS

The multiple regression model derived employs data in an original way and yields an accurate representation of the growth of both *O. edulis* and *C. gigas*. The inclusion of seawater temperature as a determinant of growth gives the model a flexibility not present in earlier studies. This modelling approach has the potential to be extended to other species as appropriate data becomes available.

The inclusion of an extensive set of costs associated with oyster cultivation are seen as a crucial element determining the practical use to which the analysis may be put. Previous studies have failed to base their economic analysis upon a complete costing of the production process.

The application of modelling techniques has been shown to be a cost effective way of investigating the commercial potential of a species for mariculture. Using the model and the investment appraisal technique the commercial viability of intertidal oyster culture has been quantified. The inclusion of sensitivity analysis goes some way to consider the element of uncertainty associated with such ventures.

Programmes for the planting out of oyster spat demonstrate the importance of considering both when to buy in spat and when oysters attain a marketable size. For example the model shows that 37,500 0.1 gramme *O. edulis* spat laid out in May at the Emsworth site will reach a market size of 80.5 grammes in 41 months with a survival rate of 66%. By changing the model input data it is feasible to produce similar programmes for any site or level of production.

The oyster mortality rate has important effects on the financial yield for both species. An IRR as high as 23.5% is predicted for *C. gigas* in one instance but high mortality rates at both sites render the culture of this species uneconomic.

The analysis can be used to investigate quite small changes in parameters. A 0.5^{o}C change in temperature regimes resulted in a variation of up to 6% in project IRR and significantly affected the payback period.

The importance of selecting the market size is shown in the case of *C. gigas* cultivated at Menai. Holding the oysters until they attain the larger grade increases the return on investment this project realises. Such results would not be obvious from superficial studies.

Differences in the life history of the two species is shown to have considerable bearing on commercial production. It is clear that the high IRR offered by the culture of *O. edulis* is in some cases outweighed by the disadvantages of its slower growth rate.

The markets for the two species of oyster have been identified and a possible marketing strategy for cultured oysters proposed. The site, production system and market are all seen to be related factors which determine the commercial viability of oyster cultivation.

9.3 LIMITATIONS OF THE ANALYSIS

Attempts to include the availability of food as a factor governing the growth of oysters failed. Very little quantitative information regarding the relationship between type and quantity of phytoplankton food and growth rate is available. The use of a multiple regression model places a practical limit on the number of independent variables which can be included. For example to include food availability would require a value for Instantaneous Growth Rate (G_{30}), Oyster Size, Seawater Temperature and Food Availability for each observation point. Where field observations are used the practical (but not the theoretical) limit can be no more than three or four independent variables.

It is not always possible to collect the data that would be required for an ideal model. In this study the scarcity of data on the growth of *O. edulis* of less than one gramme at high seawater temperatures led to over-optimistic growth rates in one instance. The application of the model must be restricted to the temperature range on which it is based. It would not be possible to use this model to simulate the operation of a nursery to produce *O. edulis* in heated seawater effluent.

Oysters grown in the sea will exhibit a variability in growth rates as no two individuals will grow in identical conditions. As a consequence annual revenue and hence the IRR will differ from the predicted returns given by the computer model. This simplification was made to reduce the analysis to a manageable size. The use of sensitivity analysis makes allowance for such effects but the importance of growth variation in real situation must be stressed.

It has been necessary to exclude food availability from the model but this does not seriously impair the use of the model provided food levels are not limiting all year round. The poor growth performance of *C. gigas* on the south coast of England has been discussed earlier. Such results are not evident from this computer model but would be from pilot growth trials.

The valuation of the owner/ongrower's labour at agricultural wage rates has been justified previously. However, it is important to note here that if this labour is costed at market labour rates it has a marked effect on the IRR of this scale of operation. The inclusion of labour at £6,000 p.a. (1979 prices) reduces the viability of the culture of *C. gigas* to such a point that in economic terms it is marginal. Similarly the return from the culture of *O. edulis* is reduced. The assumption made regarding the cost of labour is a central element of this analysis.

If the industry develops then a larger scale of operation may reflect the potential long-term yields of such ventures more accurately. The costing of such ventures would be more speculative but could highlight areas where economies of scale could be achieved.

The emphasis throughout this study centres on intertidal oyster culture. More detailed costings of raft culture and additional observations on the growth rates such systems permit would have been useful.

The oyster industry in this country falls into two distinct categories: oyster cultivation, and oyster fishing. This work has looked in detail at the commercial viability of the former sector. The author was unable to gather comparable information regarding the economics of oyster dredging.

9.4 FUTURE DEVELOPMENTS IN OYSTER CULTIVATION

Oyster culture in the United Kingdom is technically well advanced. The expansion of this sector of aquaculture will depend on how well the structure of the industry is organised and how effectively it is represented in government circles. Shellfish farming has been no more than a 'cottage industry' but increased production will necessitate co-ordination of the whole industry. The role that co-operative marketing has to play has been discussed earlier. There are several issues common to both finfish and shellfish culture which are potential constraints on the development of aquaculture.

The extension of the official definition of 'livestock' to cover fish farming is essential if producers are to gain the same benefits as agriculture. The introduction of a system to licence sites and the granting of sole rights to the use of the foreshore would go a long way towards controlling and protecting shellfish culture.

Research effort must be orientated towards commercial and marketing topics. The long term strategy of the industry must be based on an analysis of economic and technological prospects.

The production of small oysters in upwelling systems and heated seawater effluent has great commercial potential and will reduce the ongrowing period in the sea. In the long term the importance of suspended culture should increase if the capital cost of such systems can be reduced. They offer high productivity per unit volume and the possibility of exploiting deep water sites. Future developments could extend to enterprises producing a range of high value marine species in a manner similar to the variety of crops commonly produced in agricultural units.

9.5 SUGGESTIONS FOR FUTURE RESEARCH

This study has brought to light areas where future work could be productive. Current knowledge regarding the mechanisms which control the rate of oyster growth in the sea is incomplete. Further research to establish the relationship between food availability, the physical environment and growth rate would bring benefit to systems using high stocking densities and warm water culture. In the long term studies in the field of oyster genetics could produce stock improvements. Any success in reducing the ongrowing period of *O. edulis* or improving natural spatfall would be valuable.

The model used in this analysis could be improved if more data were available on the growth of oysters at above ambient seawater temperatures. The inclusion of a distribution of oyster sizes within each batch is a refinement which could lead to more realistic production scheduling.

Production scheduling is an area where there are obvious possibilities for extending the use of the model. We are presented with a situation of two oyster species which differ markedly in the time they require to grow to a consumable size, the season when they are edible, their production cost and selling price. The producer is faced with the dilemma, whether to sell at a small size or hold his stock, sustain further mortality, and sell at a large size. Such a situation lends itself to the employment of optimisation techniques to achieve economic or technical improvement. For example the ongrower may wish to schedule production in order to maximise profit (economic) or make best use of holding facilities (technical).

The demand for oysters may be known but will differ between time periods. In such circumstances an optimal production schedule to meet the objective function may be obtained from the use of the technique of dynamic programming. The information required on costs and batch production can be generated using the model derived in this study. Dynamic programming has the further advantage of permitting decisions to be taken at several stages. Hence a production schedule could be updated as new information becomes available.

There is scope for further work to investigate the economics of other aspects of shellfish culture such as the suspended culture of oysters and scallops. Oyster production is the only section of the fishing industry in the United Kingdom for which there exists a flourishing traditional fishery alongside aquaculture. A comparison of the economics of the two sectors would be valuable.

It is hoped that this study has some practical value to individuals actively engaged in shellfish cultivation. If the opportunity arose the model could be used to either prepare production forecasts for a new venture or to simulate the operation of an existing enterprise. In this way the real contribution of this study might be established.

Appendix I

A Review of Shellfisheries and Cultivation

This brief review is intended to expand on the comments made earlier regarding the status of shellfish catches and culture in the United Kingdom. Most crustaceans and molluscs of commercial importance are discussed and it is hoped that this facilitates a better understanding of the size and structure of the shellfish market as a whole. Where appropriate the potential for cultivation is discussed. This allows comparisons with the development of oyster culture. Factors which provided the stimulus for research into the cultivation of these species are given emphasis. Throughout the latest available landing statistics are used.

1.1 CRUSTACEA

Crustaceans, in general, command a high unit price and there is a ready market for high quality shellfish of this type. The potential of cultivation has attracted considerable interest and research effort has been directed towards their culture both for repopulation purposes and for the table market. All species of commercial interest are members of the Order Decapoda, a name which describes the characteristic five pairs of walking legs. At the present time, however, the commercial production of reared crustaceans in Europe is negligible. Dependence on the exploitation of natural stocks in part accounts for the high price of these shellfish.

1.1.1 Crabs

In the last decade landings of Edible Crab (*Cancer pagurus*) have increased by 500 - 1,000 tonnes per annum, to just over 11,000 tonnes in 1979. The fishery is concentrated in England and

Wales but in many regions it is regarded as a secondary catch. On the south coast of England and the Channel Isles Spider Crabs (*Maja squinado*) are fished in appreciable numbers mainly for export to the Continent.

Crabs command a relatively low price compared to other crustaceans (Chapter 1, Table 1.1). They are often only available in the locality and processors have done little to promote crab meat. Substantial landings in the early summer can lead to a glut on the market resulting in crabs being dumped or sold at minimum prices. The absence of a firm market compared to that for other crustacea has caused fishermen, to a large extent, to ignore crab resources (McKellar, 1971).

1.1.2 Lobsters

Lobsters (*Homarus vulgaris*) are fished throughout the UK although on average 55% of the annual catch is landed in Scotland. The tonnage landed has remained stable up to 1979 when it fell slightly to 872 tonnes. Lobster first sale prices in 1980 dropped to approximately £4.4/Kg. This is below the 1979 price level and has been attributed to the import of lobsters from Canada (Anon, 1980b). However, there has been a decline in demand for lobsters on the Continent and since 70% of the home catch is exported live to this market, low demand in Europe has depressed prices generally. In the home market the rising cost of living may also have had an effect on the consumption of high price shellfish. With restaurant prices for lobster currently anything up to £8 - £10 per portion there is some weight in the argument that lobster is being priced out of the reach of many potential consumers.

The high unit price of lobsters has been a considerable stimulus to achieve commercial cultivation of this species. To date emphasis has been on culture for the repopulation of depleted stocks. In Brittany lobsters have been reared routinely to the juvenile, crawling stage for several years. The juveniles are then released on grounds which have suffered from over-fishing in the past (Kirk, 1979). Present stock management in the UK is based on a minimum landing size of 80 mm carapace length. The first attempt to licence a shellfishery is the South Wales Sea Fisheries Committee decision to introduce a system in 1980 to protect lobster and crabs stocks (Anon, 1980c).

At present there is a considerable interest in the culture of lobsters to a marketable size. It may take 6 - 7 years in the wild for a lobster to grow to a marketable size. This slow growth rate together with the lobster's aggressive, often cannibalistic behaviour, have been major constraints on the development of suitable cultivation systems. Since 1976 the MAFF at Conwy have been experimenting with an 800 litre seawater recirculation system. Fed on a diet of mussels supplemented with mysids or shrimps, market size lobsters have been produced in 126 weeks. Based on 1979 prices it has been estimated that a unit to produce 200 lobsters per annum would have a capital cost of £3,500 and annual running costs of approximately £350 per annum (Anon, 1980d). Even with an estimated mortality of 37% the unit is expected to yield a profit over a range of lobster selling prices:

Selling price	Calculated Profit for unit
£4/Kg	£286.96 p.a.
£5/Kg	£358.70 p.a.
£6/Kg	£430.44 p.a.

This system is at present experimental and has a high labour input. Commercial realisation would require the introduction of some form of automation of feeding regimes. Automated feeding systems are used on trout and salmon farms and the commercial viability of lobster cultivation seems certain.

1.1.3 Norway Lobster

Until the early 1950s the Norway Lobster (*Nephrops norvegicus*) had little commercial value in Britain. Around the British Isles Norway Lobsters were commonly caught in trawls in association with fish species. More recently there has been a tremendous expansion in fishing activity for this species, such that it is now the most important shellfish harvested in the United Kingdom (Chapter 1, Table 1.1). Nephrops is an off-shore species living in burrows which it leaves to forage mainly at dawn and dusk. It is caught in specially designed 'prawn' trawls with a minimum mesh size of 70 mm (Thomas, 1970). The bulk of the catch is processed and the tails sold as 'scampi'. Much of the UK catch is exported as frozen tails. In view of its preference for an offshore environment, burrowing habit and probable aggressive behaviour the Norway Lobster is not a candidate for cultivation.

Natural stocks are adequate for the present level of fishing activity. The last year has witnessed considerable stockpiling in cold stores and this market glut has depressed prices. The normal season is for a catching peak in summer with landings falling off in winter when accummulated, frozen stock is used by processors. In 1979, with many vessels from the inshore finfish fleet trawling for 'scampi' catches did not fall off and processors began to stockpile. With so much capital tied up in stock the processors reduced their purchases in 1980. The strong Pound at the time made the export of scampi more difficult and aggravated the situation.

In the long term the future of this shellfishery is bright but it will necessitate action by the industry to regulate the level of fishing.

1.1.4 <u>Shrimps</u>

The term 'shrimps' is used to describe a number of species since identification to species level is a problem. It is possible that a distinction could be made based on size since prawns (*Palaemon serratus*) are larger than shrimps (*Crangon crangon* and *Pandalus spp*). All are species which command a high unit price and for which important commercial fisheries exist. Together these species constitute the swimming decapods or Natantia and have demonstrated potential for artificial rearing.

Several problems have been identified with the culture of these species including cannibalism, disease, slow growth and feed costs. However, the MAFF has successfully developed a system for prawn culture based on very intensive culture using controlled environment tanks (Wickens and Beard, 1978). The optimum culture temperature is in the range 20 - 28°C which is higher than ambient seawater temperatures in the British Isles. The cost of heating seawater is likely to be the major constraint on the development of prawn or shrimp culture in the UK. Commercial developments will almost certainly be restricted to where low cost, heated seawater of an acceptable quality is readily available.

1.2 MOLLUSCS

In western Europe the rearing of molluscs is without doubt the most important sector of the aquaculture industry. It has been estimated that the cultivation of molluscs accounts for 98% by weight of all marine species reared (Kirk, ibid). In France oyster cultivation accounted in 1979 for 14.5% of all marine species landed. The blue mussel (*Mytilus edulis*) is the most important single species fished in the Netherlands. Landings of 97,414 tonnes in 1979 represented 30% of the country's total marine catch. Mussels are also a significant catch in Ireland, Denmark, Spain and France.

There are approximately ten species of marine molluscs which are fished or cultured on a commercial basis in the United Kingdom. Many of these activities are regional in nature, and by comparison with their Continental counterparts, small in their scale of operation. In the UK, consumer preference is for relatively large specimens of molluscs.

1.2.1 Cockles

The Edible Cockle (*Cardium edule*) occurs all around the coast of the British Isles but is particularly abundant on the intertidal flats of large estuaries. The major commercial fisheries are in the Wash, Thames Estuary and Barry Inlet, South Wales (Walne and Wood, 1973). There is a smaller fishery in Morcambe Bay but outside England and Wales no significant landings are recorded (FAO, 1980). The 1979 landings of 10,415 tonnes makes this the most heavily fished bivalve mollusc in the United Kingdom.

Cockles occur in beds at densities as high as $500/m^2$ and are normally located just below the surface of the substrate. Their small size and sedentary, gregareous behaviour makes it particularly suitable for mechanical harvesting. The introduction of the continuous delivery hydraulic dredge has markedly increased the efficiency of cockle fishing and made accessible sublittoral cockle beds which were previously unexploited.

Commercial dredging of cockles is concentrated in the South-east of England. On the Barry Inlet fishery mechanical methods of harvesting are not permitted. Natural stocks are abundant in many localities and are readily accessible. This is one factor which may explain the low unit value of cockles. It is highly unlikely that the commercial cultivation of cockles will be contemplated. Cultivation would require the use of extensive intertidal areas and be very labour intensive. The inclusion of cooking and processing equipment would further increase the cost of cultivation.

1.2.2 Mussels

Most natural stocks of mussels are not suitable for commercial exploitation because of poor meat quality resulting from overcrowding, overexposure to air or wave action. Cultivation overcomes these problems by thinning out beds and relaying of seed mussels in suitable areas. Cultivated mussels usually command a better price than their wild counterparts as they are normally of a better quality. Over 95% of the British catch comes from managed mussel beds.

Commercial production of mussels (*Mytilus edulis*) is centred on the Wash, Norfolk, North Wales and Teignmouth in Devon. Landings over the last decade have averaged 6,000 - 7,000 tonnes p.a. Depending on the site mussels require one to three years to reach the minimum UK market size of 50 mm length. Harvesting is normally carried out between the months September to March. Mussel beds are highly productive in terms of flesh per unit area of lay. A well-managed bed will produce 100 - 125 tonnes live weight of mussel per hectare every two years (Anon, 1980e). It is estimated that there are 300 - 400 hectares of intertidal and subtidal lay-ground suitable for mussel culture in England and Wales. The potential yield from these grounds is estimated at 25,000 tonnes p.a.

Mussel beds are well suited to the use of mechanisation. The Menai Strait fishery in North Wales is mechanised throughout. A variety of mechanical and suction dredges are employed for harvesting and removal of starfish predators. In Brittany amphibious craft with a crew of five and a loading capacity of six tonnes of mussels are used for harvesting (Anon, 1980f). Such forms of mechanisation drastically reduce the cost of harvesting. However, because of their thin shell mussels are very susceptible to damage through rough handling (Dare, 1977). The use of mechanical harvesting and sorting has been shown to cause a 21% loss in keepability as measured by accelerated mortality over a 72 hour period (Anon, 1978).

Mussel cultivation is relatively straight-forward but is at present constrained by irregular supplies of seed mussels and poor survival of relaid seed due chiefly to predators. The latter could be avoided by the use of protective fencing or suspended culture but the low price of mussels (£49/tonne in 1979) does not justify the capital cost and labour input required. British production at present goes mainly to the home market and is supplemented by frozen imports from the Continent. The three main producers, the Netherlands, Spain and France, in 1979 produced over 200,000 tonnes of *M. edulis* and by comparison the UK output is small. In the future British producers could make inroads into the European market if they produced a smaller mussel of 40 - 50 mm. This is the size preferred on the Continent and would also reduce growing time and hence costs.

1.2.3 Scallops and Queens

The Scallop (*Pecten maximus*) is common around the British Isles, usually on bottoms of sand or muddy gravel. Its commonest depth is 10 - 20 fathoms. The Queen Scallop (*Chlamys opercularis*) is often found with *P. maximus* but is smaller, rarely exceeding 10 cm shell length. This species has two rounded shell valves and is a more active swimmer than the true scallop.

The fishery for these species was negligible in England and Wales until the late 1960s although it has been well established in Scotland and the Isle of Man for a number of years. The pattern of landings has been affected by the availability of more highly prized finfish species and by the development of overseas markets for scallops. The main fisheries are found on the West Coast; Clyde area of Scotland, Isle of Man, South-west of England, and English Channel. Catches are taken using dredges of between 1 - 2 metre width (Melhuish, 1980). Fishing intensity on these stocks is increasing. In 1978 in England and Wales there were 130 vessels engaged in scallop fishing, 60% of which were based in Plymouth or Brixham (Franklin et al, 1980). Landings from the south-west and Channel areas are increasing as new stocks are being discovered. The value of this fishery is currently over £2 million per annum.

The future of these fisheries is uncertain. Fishing pressure is increasing and the high catch rates are sustained by the exploitation of virgin grounds. Natural recruitment of scallops and queens is variable and for the scallop individuals do not enter the fishery until they are 3 - 4 years old.

The problem of heavy fishing has been the stimulus for research into the potential of cultivation of the Family Pectinidae. Hatchery techniques for the production of scallop spat have been formulated but have not been as successful as techniques for the production of juvenile molluscs of other species. Research emphasis is now concentrated towards the development of effective collectors for scallop spat. The use of subsurface collection bags anchored over spawning parent stock to collect natural spatfall appears to be the most commercially promising method (Slater, 1979). Several workers have concluded that bottom culture where scallops are grown to market size in underwater corrals and suspended net culture offer the best commercial opportunities. It is estimated that a small unit to produce 15 to 18 tonnes of net cultured scallops per annum would require a capital investment in the region of £25,000 and have operating costs of £10,000 p.a. This scale of enterprise could yield a revenue of between £10,000 and £20,000 p.a. (Anon, 1981).

It is relatively easy to catch and grow the queen scallop, *C. opercularis*. This smaller species, however, commands a lower unit price than the true scallop (Chapter 1, Table 1.1) and as a more active swimmer is less suited to cultivation (Picket, 1979).

1.2.4 Clams

There are no commercial fisheries for clams in the United Kingdom although after oysters these species offer the most immediate potential for cultivation. The Palourde (*Venerupis decussata*) is not uncommon in Britain, buried deeply in muddy grounds, but so far has not been found in commercial quantities. There is a strong demand for this species in France which cannot be met by French producers. At present France imports hundreds of tonnes of this shellfish principally from Spain. The second species of interest is the American Hard Clam or Quahog (*Mercenaria mercenaria*). This species supports a valuable fishery on the eastern coast of North America. Clams of over 7 cm length are known as 'Chowder Clams' and are processed into soup or canned. The Quahog is not native to Europe but growth trials at Conwy have successfully reared this species (Walne, 1974). A population of this species was discovered to have established itself in Southampton Water from an earlier introduction (Ansell, 1963).

Hatchery rearing techniques for both species are developed and many commercial hatcheries in the UK already offer *V. decussata* spat for the industry. The clams may be either planted out in 'parcs', on-grown in suspended mesh bags or reared by a combination of both. All these methods are well established for oyster cultivation. In the Bay of Bourgneuf on the Atlantic coast of

France cultivation of the Palourde is carried out in conjunction with oyster culture. The clams use the oyster ponds during the period March to September when they are not fully utilised on oyster production (Anon, 1979c).

The Palourde grows best if allowed to burrow, however, it burrows to a depth of 7 - 10 cm from where it is difficult to harvest. This species is marketed at 8 - 9 grammes (30 - 40 mm length) and requires approximately two years to achieve this size (Lucas, 1976). Culture trials performed by the MAFF found that 10^5 10 mm spat would be required to yield one tonne of *V. decussata* of 50 mm average size after three years growth (Walne, 1976). This slow growth rate has focussed attention on the possibility of importing a faster growing species. Interest centres on the Manila clam (*Venerupis semi-decussata*) of Indo-Pacific origin. This introduction may be compared to the earlier introduction of the fast growing Pacific Cupped Oyster (*Crassostrea gigas*). The cultivation of *V. semi-decussata* has excellent commercial potential with success most likely to be achieved by making use of suspended culture methods which have been shown to give both high survival and rapid growth (Kirk, ibid).

The culture potential of the Quahog is less certain. This species will thrive in soft muddy areas unsuitable for other types of shellfish and only burrows to just below the substrate surface. However, this clam is also relatively slow growing in European waters. Samples grown at Conwy took 16 months to grow from 1 - 5 grammes to 9 gramms (Walne and Dean, 1967). Survival rates of up to 80% over the two year growing period may be achieved if plastic mesh covering is used. Unprotected Quahogs are readily attacked by crabs.

The consumption of clams in the United Kingdom is negligible but there is considerable potential for cultivation to export to France. Clam culture utilises hatchery and ongrowing techniques which have been developed and proven for oyster cultivation. A unit to produce both clams and oysters offers the ongrower both a wider product range and the possibility of more efficient utilisation of equipment.

1.2.5 Whelks, Winkles and Ormers

These species are gastropods, having a single shell, whereas the previous species were all bivalves whose body is laterally compressed and enclosed within two valves or shells.

The Whelk (*Buccinum undatum*) is a marine snail, very common all around the British Isles and found sublittorally on a sandy or muddy bottom. The commercial fishery is restricted to shallow waters off Grimsby, East Anglia and Kent. Whelks are usually caught in baited pots. The best commercial size is small, up to 70 mm overall length. This species has no pelagic phase in its life history, so recruitment of young whelks is sensitive to the stability of the parent stock.

As with the whelk, the distribution of the winkle (*Littorina littorea*) is very much wider than the fishery for them. Gathering is almost exclusively by hand and performed on a part-time basis. Sephton (1980) in his study of the Scottish periwinkle fishery states that the bulk of the British landings are exported to the Continent where demand is much greater than on the home market. He concluded that the United Kingdom demand was unlikely to significantly increase in the foreseeable future. Natural stocks of both the whelk and the winkle are adequate to supply the present level of demand. The cultivation of either species seems improbable.

The Ormer (*Haliotis tuberculata*) is a type of limpet whose British distribution only extends to the Channel Isles. The main market is France and harvesting is confined to France, the Channel Isles and the Iberian Peninsula. The Ormer commands a high price but there is little organised exploitation. It is unlikely that there is more than a fairly small outlet for this species. Locally some intertidal stocks may be heavily exploited but stocks further down the littoral zone are almost totally unexploited.

1.3 COMMENT

In this review discussion has been limited to those species of shellfish which are marketed or cultured in a similar way to oysters. No attempt has been made to review the culture of finfish or to present an exhaustive list of shellfish. Considerable research effort has been expended to develop culture techniques for those species of shellfish for which natural stocks are unsuitable or inadequate. The priority with which this goal has been pursued has reflected the unit price of the species. Viewed in these terms the oyster is a prime candidate for cultivation.

Appendix II

The Calculation of a Complete Investment Appraisal

All investment appraisals utilise revenue data derived from the multiple regression growth model and cost information included in Chapter 6.

1. **Revenue**

The annual income accrued from the sale of mature oysters is derived from the value figure calculated in the computer growth model; 'OYMOD' (Figure B). The model computes the stock value at harvesting based on an initial 100,000 spat for each month of planting out. The projected annual crop value is composed of a proportion from each of the months when spat were laid out.

Example: Production of 100,000 oysters of species *C. gigas* grown from 0.1 gramme spat at Emsworth site

Month laid out	Proportion of Annual Revenue from each batch		
April	0.3375* x £ 8,355.16†	=	£ 2,819.87
May	0.3375* x £11,710.05†	=	£ 3,952.14
June	0.3375* x £11,744.40†	=	£ 3,963.74
July	0.3375* x £11,864.25†	=	£ 4,004.18
	TOTAL		£14,739.93

* From Table 7.1 Model employes a figure of 100,000 spat per month.

† Stock value predicted by 'OYMOD' model for harvesting month (Figure D).

A similar calculation has been performed to calculate the revenue accrued in each of the other appraisals.

2. Costs

All costs used in the analysis are drawn from the data given in Chapter Six. For the purpose of performing the investment analysis it is necessary to establish for each appraisal:

(i) The capital expenditure in Year 0.
(ii) The annual depreciation charge.
(iii) A cash outflow matrix over the project life.
(iv) An income statement to determine Tax liability.

To illustrate the procedure the costs for the above example to produce 100,000 mature *C. gigas* from 0.1g spat at the Emsworth site will be as follows:

(i) Capital Expenditure in Year 0 (1979)

Item	Cost (£)
Building	2,000
Boat	2,500
Vehicle	3,165
Trays / Bags	2,270
Purification Plant	300
Site Survey	900
Working Capital	4,000
Insurance	200
Protective Fencing	150
Miscellaneous Items	250
	£ 15,735

(ii) Annual Depreciation Charge

Item	Cost (£) Yrs 1 - 10	Scrap Value (£) Yr 11
Building	200	
Boat	250	
Vehicle	803	(1,704)
Trays / Bags	454	
Purification Plant	30	
Protective Fencing	50	(100)
Miscellaneous	85	
TOTAL	£ 1,872	£(1804)

(iii) <u>Cash outflow matrix over full project life</u> (Table A.1)

ITEM	YEAR											
	0	1	2	3	4	5	6	7	8	9	10	11
Capital Investment	15,735											
Spat Cost		1,029	1,029	1,029	1,029	1,029	1,029	1,029	1,029	1,029	1,029	
Labour		3,750	3,750	3,750	3,750	3,750	3,750	3,750	3,750	3,750	3,750	
Running Costs: Vehicles		1,140	1,140	1,140	1,140	1,140	1,140	1,140	1,140	1,140	1,140	
Replacement Trays and Bags							2,270					
Replacement Vehicles and Tyres					317	3,028		317		3,028	317	(1,704)
Purification and Packaging		435	435	435	435	435	435	435	435	435	435	
Fencing and Sea Bed Rent		20	20	20	170	20	20	250	100	100	100	(100)
Miscellaneous			150		150		150		150		150	(75)
Overheads		825	825	825	825	825	825	825	825	825	825	
Maintenance		380	380	380	380	380	380	380	380	380	380	
Insurance and Licences		471	471	471	471	471	471	471	471	471	471	
Marketing*												900
TOTAL	15,735	8,050	8,200	8,050	8,667	11,078	10,470	8,597	8,280	11,158	8,597	(979)

*This is the cost of selling stock laid out as 0.1g spat in Year 10. A similar cost is included in other appraisals where slower growth rates necessitate marketing in any of the years 12 - 14 of the Project.

(iv) Income Statement to Calculate Tax Liability

The payment of tax in the study has been lagged by one year. To calculate the annual tax liability an income statement based on standard costs is required. For the example it is derived as follows:

Item	Annual Standard Cost (£) Years 1 - 10
Labour	3,750
Annual Depreciation	1,872
Running Costs, Vehicles	1,140 (10,000 miles p.a.)
Spat Cost	1,029
Overheads	825
Insurance and Licences	471
Purification and Packaging	435
Maintenance	380
Sea bed Rent	£20 years 1 - 6 / £100 years 7 - 10
TOTAL COST	£9,924 (Yrs 1-6) £10,004 (Yrs 7-10)

The tax brackets employed in preparing the income statement are the personal income tax rates outlined in Section 6.12.

Table A.2 Income Statement

Year	Costs	Revenue	Gross Income	Taxation	Taxation Lagged 1 yr
0	1,100*	-	(1,100)	(330)	0
1	9,924	-	(9,924)	(2,977)	330
2	9,924	14,740	4,816	1,445	(2,977)
3	9,924	14,740	4,816	1,445	1,445
4	9,224	14,740	4,816	1,445	1,445
5	9,924	14,740	4,816	1,445	1,445
6	9,924	14,740	4,816	1,445	1,445
7	10,004	14,740	4,736	1,421	1,445
8	10,004	14,740	4,736	1,421	1,421
9	10,004	14,740	4,736	1,421	1,421
10	10,004	14,740	4,736	1,421	1,421
11	(979)	14,740	15,719	1,421	1,421
12	-	-	-	-	1,421

*Non-depreciable set up costs, i.e. site survey and insurance.

All the information presented to date may now be drawn together and the net cash flows after tax for the project calculated. The derived figures are shown in Table A.3. A computer programme to perform investment appraisals (INVANL) is used to determine the rate of return of the proposed operation. The inputs for the package are: Revenue, Total after tax cost, net initial investment, and project life. All data is drawn from Table A.3.

Table A.3 Calculation of the Net After Tax Cash Flows

Year	Revenue	Pre-Tax Cost	Pre-Tax Gross Income	Tax Due	Total After Tax Cost	Net Cash Flow After Tax
0	-	15,735	(15,735)	-	15,735	(15,735)
1	-	8,050	(8,050)	(330)	7,720	(7,720)
2	14,740	8,200	6,540	(2,977)	5,224	9,517
3	14,740	8,050	6,690	1,445	9,495	5,245
4	14,470	8,667	6,073	1,445	10,112	4,628
5	14,470	11,078	3,662	1,445	12,523	2,217
6	14,470	10,470	4,270	1,445	11,915	2,825
7	14,740	8,597	6,143	1,445	10,042	4,698
8	14,740	8,280	6,460	1,421	9,701	5,039
9	14,740	11,158	3,582	1,421	12,579	2,161
10	14,740	8,597	6,143	1,421	10,018	4,722
11	14,740	(979)	15,719	1,421	442	14,298
12	-	-	-	7,074	7,074	(7,074)

The INVANL Programme shows this project to have an IRR of 15.13% and a payback period of 5 years 2 months (Figure E).

3./

3. Other key investment appraisals

In a similar manner revenue data has been generated by the OYMOD model for the other three basic analyses. The annual revenue in each case is based on the planting out scheme given in Table 7.1 and is summarised as follows:

The calculation of annual revenue for the production of 100,000 oysters per annum from 0.1 gramme spat for the remaining three 'key appraisals'

(a) *C. gigas* at Menai

Month laid out	Proportion of annual revenue from each batch		
April	0.45 x £8,032.86	=	£ 3,614.9
May	0.45 x £8,233.17	=	£ 3,705.1
June	0.45 x £8,310.39	=	£ 3,739.4
		TOTAL	£11,509.4

(b) *O. edulis* at Emsworth

Month laid out	Proportion of annual revenue from each batch		
May	0.375 x £19,953.90	=	£ 7,482.7
June	0.375 x £20,484.90	=	£ 7,681.8
July	0.375 x £20,665.32	=	£ 7,749.5
August	0.375 x £22,038.90	=	£ 8,264.6
		TOTAL	£31,179.

(c) *O. edulis* at Menai

Month laid out	Proportion of annual revenue from each batch		
May	0.50 x £13,448.76	=	£ 6,724.38
June	0.50 x £14,098.76	=	£ 7,049.38
July	0.50 x £14,915.16	=	£ 7,457.58
		TOTAL	£21,231

4. Costs employed

The capital expenditure in year zero and the annual depreciation charge in each key appraisal producing 100,000 oysters per annum is given in 2(i) and 2(ii) respectively.

In deriving the net after tax cash flows used in the investment appraisal differences arise due to:

I Revenue

II Spat requirements

III Length of project as determined by oyster growth rate

This information can be drawn together and the net cash flows after tax for each key appraisal calculated (Tables A.4 - A.6). In each case the INVANL programme has been employed to perform the investment appraisal. The results are included.

Table A.4 Investment appraisal for the production of 100,000 *C. gigas* per annum at Menai

Year	Revenue	Pre Tax Cost	Pre Tax Gross Income	Tax Due	Total After Tax Cost	Net Cash Flow After Tax
0	-	15,735	(15,735)	-	15,735	(15,735)
1	-	8,050	(8,050)	(330)	7,720	(7,720)
2	11,059	8,200	2,859	(2,976)	5,224	5,835
3	11,059	8,050	3,009	341	8,391	2,668
4	11,059	8,667	2,392	341	9,008	2,051
5	11,059	11,078	(19)	341	11,419	(360)
6	11,059	10,470	589	341	10,811	248
7	11,059	8,597	2,462	341	8,938	2,121
8	11,059	8,280	2,779	317	8,597	2,462
9	11,059	11,158	(99)	317	11,475	(416)
10	11,059	8,597	2,462	317	8,914	2,145
11	11,059	(979)	12,038	317	317	10,742
12	-	-	-	5,417	5,417	(5,417)

RESULT Outlay exceeds income over project life by £397.

Table A.5 /

Table A.5 Investment appraisal for the production of 100,000 *O. edulis* per annum at Emsworth

Year	Revenue	Pre Tax Cost	Pre Tax Gross Income	Tax Due	Total After Tax Cost	Net Cash Flow After Tax
0	-	15,735	(15,735)	-	15,735	(15,735)
1	-	8,410	(8,410)	(330)	8,080	(8,080)
2	-	8,560	(8,560)	(3,000)	5,560	(5,560)
3	-	8,410	(8,410)	(3,000)	5,410	(5,410)
4	31,179	9,027	22,152	0	9,027	22,152
5	31,179	11,438	19,741	9,404	20,842	10,337
6	31,179	10,830	20,349	9,404	20,234	10,945
7	31,179	8,957	2,222	9,404	18,361	12,818
8	31,179	8,640	22,539	9,368	18,008	13,171
9	31,179	11,518	19,661	9,368	20,886	10,293
10	31,179	8,957	22,222	9,368	18,325	12,854
11	31,179	(879)*	32,058	9,368	8,489	22,690
12	31,179	900†	30,279	14,426	15,326	15,853
13	31,179	900†	30,279	13,626	14,526	16,653
14	-	-	-	13,626	13,626	(13,626)

* Assuming protective fencing employed till year 13 reduces scrap value by £100.

† Marketing cost.

<u>RESULTS</u> Payback of initial investment is in 5 years 1 month

Rate of return equating present value of cash flow to zero is 23.48%

Table A.6 /

Table A.6 Investment appraisal for the production of 100,000 *O. edulis* per annum at Menai

Year	Revenue	Pre Tax Cost	Pre Tax Gross Income	Tax Due	Total After Tax Cost	Net Cash Flow After Tax
0	-	15,735	(15,735)	-	15,735	(15,735)
1	-	8,410	(8,410)	(330)	8,080	(8,080)
2	-	8,560	(8,560)	(3,000)	5,560	(5,560)
3	-	8,410	(8,410)	(3,000)	5,410	(5,410)
4	-	9,027	(9,027)	0	9,027	(9,027)
5	21,231	11,438	9,793	0	11,438	9,793
6	21,231	10,830	10,401	4,380	15,210	6,021
7	21,231	8,957	12,274	4,380	13,337	7,894
8	21,231	8,640	12,591	4,348	12,988	8,243
9	21,231	11,518	9,713	4,348	15,866	5,365
10	21,231	8,957	12,274	4,348	13,305	7,926
11	21,231	(879)	22,110	4,348	2,469	17,762
12	21,231	900	20,331	9,950	10,850	10,381
13	21,231	900	20,331	9,149	10,049	11,182
14	21,231	900	20.331	9,149	10,049	11,182
15	-	-	-	9,149	9,149	(9,149)

RESULTS Payback of initial investment is in 9 years 4 months

Rate of return equating present value of cash flow to zero is 9.33%

Figure A <u>Computer Programme listing for the von Bertalannfy growth model</u>

```
*     PROGRAM FOR VON BERTALANFFY OYSTER GROWTH MODEL
      DIMENSION WT(100),B1(100),B2(100),NUM(100),VAL(100)
      DIMENSION WO(100),Z30(100),R1(100),R2(100),R3(100),INUM(100)
      READ(05,01) MSPEC,T,INUM(1)
      WRITE(06,01) '  N      TIME       SIZE        NUMBER     VALUE'
01    FORMAT(V)
      N=1
      WO(1)=0.10
      DO 13 I=1,100
      IF(MSPEC.EQ.1) GOTO 03
      Z30(I)=0.02614*WO(I)**(-0.415356)
      R1(I)=ALOG(INUM(I))
      R2(I)=R1(I)-Z30(I)
      R3(I)=EXP(R2(I))
      NUM(I)=IFIX(R3(I))
      B1(I)=0.276*(T+1.011)
      B2(I)=1-(0.3676**B1(I))
      WT(I)=(5.29*B2(I))**3
      GOTO 05
03    Z30(I)=0.02614*WO(I)**(-0.415356)
      R1(I)=ALOG(INUM(I))
      R2(I)=R1(I)-Z30(I)
      R3(I)=EXP(R2(I))
      NUM(I)=IFIX(R3(I))
      B1(I)=0.3183*(T+0.4071)
      B2(I)=1-(0.3676**B1(I))
      WT(I)=(9.94*B2(I))**2.0
05    IF(WT(I).GE.90.00) GOTO 15
      IF(MSPEC.EQ.1) GOTO 07
      IF(WT(I).LE.50.00)  VAL(I)=0.0276*NUM(I)*WT(I)**0.4148
      IF(WT(I).GE.50.01.AND.WT(I).LE.59.99) VAL(I)=NUM(I)*0.185
      IF(WT(I).GE.60.00.AND.WT(I).LE.69.99) VAL(I)=NUM(I)*0.23
      IF(WT(I).GE.70.00.AND.WT(I).LE.79.99) VAL(I)=NUM(I)*0.26
      IF(WT(I).GE.80.00.AND.WT(I).LE.90.00) VAL(I)=NUM(I)*0.30
      GOTO 09
07    IF(WT(I).LE.59.99) VAL(I)=0.0147*NUM(I)*WT(I)**0.2909
      IF(WT(I).GE.60.00.AND.WT(I).LE.74.99) VAL(I)=NUM(I)*0.11
      IF(WT(I).GE.75.00.AND.WT(I).LE.90.00) VAL(I)=NUM(I)*0.15
09    WRITE(06,11) N,T,WT(I),NUM(I),VAL(I)
11    FORMAT(I4,2F10.3,I12,F10.2)
      WO(I+1)=WT(I)
      INUM(I+1)=NUM(I)
      T=T+0.083333
      N=N+1
13    CONTINUE
15    PRINT,"OYSTER SIZE TOO LARGE"
      STOP
      END
```

Figure B <u>Computer programme listing for the 'OYMOD' multiple regression model</u>

```
*       PROGRAM FOR OYSTER GROWTH + MORTALITY:- ' OYMOD '
        REAL ST(12)/07.00,07.00,08.20,09.20,12.50,15.00,17.20,
&       17.00,15.20,13.10,08.00,07.40/
        DIMENSION C1(100),C2(100),Y(100),MONTH(100),B2(100)
        DIMENSION G30(100),WT(100),A1(100),A2(100),NUM(100),Z30(100)
        DIMENSION F1(100),F2(100),B1(100),B3(100),VAL(100),AREA(100)
        CHARACTER*3 YES/"YES"/
        PRINT," "
        PRINT,"DO YOU REQUIRE INSTRUCTIONS: YES OR NO"
        PRINT," "
        READ(05,01) YES
01      FORMAT(A3)
        IF(YES.NE."YES") GOTO 03
        PRINT," "
        CALL RULES
03      PRINT," "
        PRINT,"   OYSTER GROWTH AND MORTALITY MODEL:-OYMOD"
        PRINT," "
        READ(05,05) MSPEC,MONTH(1),WT(1),NUM(1),MORT
        WRITE(06,05) "MONTH TEMP(oC) SIZE(g) NUMBER   VALUE    AREA(m2) K"
05      FORMAT(V)
        K=1
*       CALCULATE MONTHLY MORTALITY
        DO 25 I=1,100
        GOTO(07,09,11),MORT
07      Z30(I)=0.009928*WT(I)**(-0.544602)
        GOTO 13
09      Z30(I)=0.026144*WT(I)**(-0.415356)
        GOTO 13
11      Z30(I)=0.056804*WT(I)**(-0.4607479)
13      B1(I)=ALOG(NUM(I))
        B2(I)=B1(I)-Z30(I)
        B3(I)=EXP(B2(I))
        NUM(I+1)=IFIX(B3(I))
*       CAL.MONTHLY GROWTH FROM INITIAL WT.+TEMP.
        A2(I)=ALOG10(ST(MONTH(I)))
        A1(I)=ALOG10(WT(I))
        IF(MSPEC.EQ.1) GOTO 15
        C1(I)=0.55854*(A1(I)-0.746237)
        C2(I)=5.17259*(A2(I)-1.13207)
        Y(I)=((C2(I)-C1(I))-1.01194)
        GOTO 17
15      C1(I)=0.32901*(A1(I)-0.202624)
        C2(I)=1.67674*(A2(I)-1.13475)
        Y(I)=((C2(I)-C1(I))-0.2922608)
17      G30(I)=10**Y(I)
        WT(I+1)=WT(I)*EXP(G30(I))
```

Figure B (continued)

```
*       REQUIRED AREA FOR OYSTER GROWTH
        AREA(I)=0.0002*WT(I+1)*NUM(I)
        IF(WT(I+1).GE.90.00) GOTO 27
        IF(MSPEC.EQ.1) GOTO 19
*       CAL.STOCK VALUE FROM SIZE + NUMBER
        IF(WT(I+1).LE.05.00) VAL(I)=0.01795*NUM(I+1)*WT(I+1)**0.2652
        IF(WT(I+1).GE.40.00.AND.WT(I+1).LE.49.99) VAL(I)=NUM(I)*0.16
        IF(WT(I+1).GE.50.00.AND.WT(I+1).LE.59.99) VAL(I)=NUM(I+1)*0.185
        IF(WT(I+1).GE.60.00.AND.WT(I+1).LE.69.99) VAL(I)=NUM(I+1)*0.23
        IF(WT(I+1).GE.70.00.AND.WT(I+1).LE.79.99) VAL(I)=NUM(I+1)*0.26
        IF(WT(I+1).GE.80.00.AND.WT(I+1).LE.90.00) VAL(I)=NUM(I+1)*0.30
        GOTO 21
19      IF(WT(I+1).LE.05.00) VAL(I)=0.0137*NUM(I+1)*WT(I+1)**0.2538
        IF(WT(I+1).GE.60.00.AND.WT(I+1).LE.74.99) VAL(I)=NUM(I+1)*0.11
        IF(WT(I+1).GE.75.00.AND.WT(I+1).LE.90.00) VAL(I)=NUM(I+1)*0.15
21      WRITE(06,23) MONTH(I),ST(MONTH(I)),WT(I+1),NUM(I+1),VAL(I),AREA(I),K
23      FORMAT(I4,F9.2,F8.2,I9,F10.2,F9.2,I3)
        MONTH(I+1)=MONTH(I)+1
        K=K+1
        IF(MONTH(I+1).EQ.13) MONTH(I+1)=1
25      CONTINUE
27      WRITE(06,29) MONTH(I)
29      FORMAT(I4,4X,22HSTOCK OVER MARKET SIZE)
        PRINT," "
        PRINT,"IS ANOTHER BATCH TO BE LAID OUT:YES OR NO"
        PRINT," "
        READ(05,31) YES
31      FORMAT (A3)
        IF(YES.EQ."YES") GOTO 03
        STOP
        END
        SUBROUTINE RULES
        PRINT,"MODEL INPUT:SPECIES(1=C.GIGAS,2=O.EDULIS),MONTH SET OUT"
        PRINT,"(JAN=1,DEC=12),INITIAL SIZE(G),INITIAL NUMBER AND THE"
        PRINT,"DESIRED MORTALITY RATE(1=LO,2=MED,3=HI). GROWTH RATE(G30)"
        PRINT,"IS CALCULATED FROM THE LOG10 MULTIPLE REGRESSION;"
        PRINT," "
        PRINT,"          Y = A0 + A1X1 + A2X2"
        PRINT," "
        PRINT,"  WHERE   Y=LOG(G30), X1=LOG(SIZE), X2=LOG(TEMP) "
        PRINT," "
        PRINT,"MONTHLY MORTALITY(Z30) CALCULATED FROM SIZE(W0(I)) "
        PRINT,"GROWING AREA(m2/1000) BASED ON NUM AT MONTH START"
        PRINT,"& SIZE AT END MONTH; STOCK DENSITY 0.5g/m2 "
        RETURN
        END
```

Figure C Flow diagram for the 'OYMOD' multiple regression model

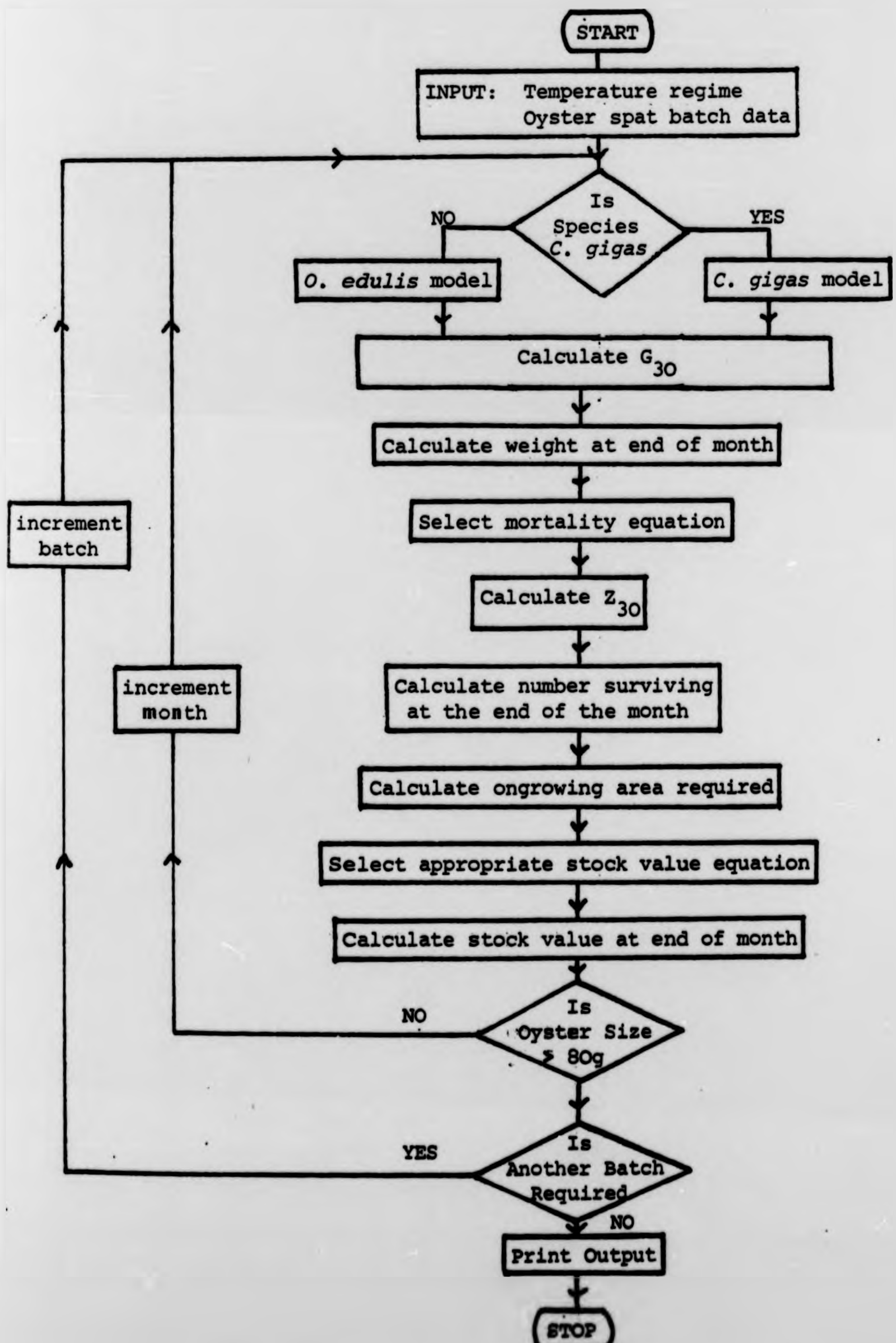


Figure D Output of the 'OYMOD' computer model: The production of 100,000 mature *Crassostrea gigas* from 0.1 gramme spat laid out in batches April - July at the Emsworth site

OYSTER GROWTH AND MORTALITY MODEL:-OYMOD

MONTH	TEMP(oC)	SIZE(g)	NUMBER	VALUE	AREA(m2)	K
● 4	10.50	0.23	93422	878.18	4.53	1
5	15.00	0.71	89005	1116.56	13.21	2
6	15.00	1.55	86357	1321.24	27.51	3
7	18.75	3.72	84492	1615.84	64.28	4
8	18.50	7.08	83221	0.	119.72	5
9	16.50	10.89	82261	0.	181.25	6
10	14.30	14.61	81467	0.	240.29	7
11	11.00	17.34	80770	0.	282.54	8
12	7.50	18.89	80126	0.	305.09	9
1	6.00	20.00	79510	0.	320.44	10
2	5.30	20.93	78913	0.	332.78	11
3	6.30	22.22	78331	0.	350.68	12
4	10.50	25.52	77768	0.	399.73	13
5	15.00	32.45	77240	0.	504.69	14
6	15.00	40.52	76765	0.	625.92	15
7	18.75	54.70	76334	8396.74	839.80	16
●● 8	18.50	71.36	75956	8355.16	1089.39	17
9	16.50	87.25	75619	11342.85	1325.40	18
10	STOCK OVER MARKET SIZE					

OYSTER GROWTH AND MORTALITY MODEL:-OYMOD

MONTH	TEMP(oC)	SIZE(g)	NUMBER	VALUE	AREA(m2)	K
5	15.00	0.44	93422	1040.96	8.86	1
6	15.00	1.10	90058	1264.86	20.61	2
7	18.75	2.95	87825	1582.72	53.05	3
8	18.50	5.90	86371	0.	103.68	4
9	16.50	9.32	85297	0.	160.95	5
10	14.30	12.69	84419	0.	216.51	6
11	11.00	15.19	83654	0.	256.49	7
12	7.50	16.61	82950	0.	277.87	8
1	6.00	17.63	82277	0.	292.44	9
2	5.30	18.48	81626	0.	304.16	10
3	6.30	19.67	80993	0.	321.19	11
4	10.50	22.72	80381	0.	368.05	12
5	15.00	29.17	79808	0.	468.88	13
6	15.00	36.71	79295	0.	585.94	14
7	18.75	50.05	78832	8671.52	793.76	15
8	18.50	65.81	78427	8626.97	1037.59	16
●● 9	16.50	80.90	78067	11710.05	1269.01	17
10	STOCK OVER MARKET SIZE					

● Denotes April

●● Month of harvesting

Figure D (continued)

OYSTER GROWTH AND MORTALITY MODEL:-OYMOD

MONTH	TEMP(oC)	SIZE(g)	NUMBER	VALUE	AREA(m2)	K
6	15.00	0.44	93422	1040.96	8.86	1
7	18.75	1.67	90058	1404.96	31.17	2
8	18.50	3.86	88174	1701.61	69.48	3
9	16.50	6.52	86867	0.	115.00	4
10	14.30	9.23	85830	0.	160.38	5
11	11.00	11.27	84943	0.	193.48	6
12	7.50	12.44	84134	0.	211.28	7
1	6.00	13.28	83365	0.	223.43	8
2	5.30	13.99	82623	0.	233.23	9
3	6.30	14.98	81904	0.	247.51	10
4	10.50	17.53	81211	0.	287.21	11
5	15.00	23.01	80567	0.	373.78	12
6	15.00	29.51	79996	0.	475.50	13
7	18.75	41.17	79484	0.	658.76	14
8	18.50	55.13	79041	8694.51	876.40	15
9	16.50	68.62	78651	8651.61	1084.76	16
●●10	14.30	80.54	78296	11744.40	1266.97	17
11	11.00	88.83	77965	11694.75	1390.97	18
12	STOCK OVER MARKET SIZE					

OYSTER GROWTH AND MORTALITY MODEL:-OYMOD

MONTH	TEMP(oC)	SIZE(g)	NUMBER	VALUE	AREA(m2)	K
7	18.75	0.87	93422	1235.60	17.41	1
8	18.50	2.46	90870	1564.15	45.93	2
9	16.50	4.52	89249	1793.03	82.14	3
10	14.30	6.69	88010	0.	119.40	4
11	11.00	8.35	86971	0.	147.01	5
12	7.50	9.31	86034	0.	161.93	6
1	6.00	10.01	85148	0.	172.16	7
2	5.30	10.59	84297	0.	180.41	8
3	6.30	11.42	83474	0.	192.51	9
4	10.50	13.56	82684	0.	226.45	10
5	15.00	18.23	81955	0.	301.54	11
6	15.00	23.85	81315	0.	390.92	12
7	18.75	34.09	80747	0.	554.44	13
8	18.50	46.51	80261	0.	751.09	14
9	16.50	58.62	79836	8781.96	941.02	15
10	14.30	69.40	79452	8739.72	1108.09	16
●●11	11.00	76.91	79095	11864.25	1222.17	17
12	7.50	81.04	78755	11813.25	1282.00	18
1	6.00	83.96	78423	11763.45	1322.43	19
2	5.30	86.38	78098	11714.70	1354.77	20
3	6.30	89.68	77778	11666.70	1400.82	21
4	STOCK OVER MARKET SIZE					

Figure E <u>Output of the 'INVANL' investment appraisal programme: Example to produce 100,000 mature *Crassostrea gigas* per annum at the growth rates given in Figure D</u>

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THIS PROGRAM CALCULATES THE DISCOUNTED RATE OF RETURN
WHICH EQUATES THE PRESENT VALUE OF THE OPERATING CASH
FLOW TO ZERO. A PAYBACK PERIOD IS ALSO COMPUTED, BASED ON
NET CASH FLOW. INTEREST IS COMPUTED ON THE AVERAGE BALANCE
FOR THE YEAR. THE PROGRAM OFFERS SENSITIVITY ANALYSIS BY
ALLOWING THE USER TO CHANGE SELECTED FIGURES FOR THE
THE SAME CAPITAL INVESTMENT.


ENTER INPUT DATA:
NET INITIAL INVESTMENT IN DOLLARS ONLY(EG. -5000)
=-15735
WEIGHTED COST OF CAPITAL IN % (EG. 8.0)
=0.0
PROJECT LIFE IN YEARS
=12
OUTLAY, INCOME(SEPARATE BY COMMA;MINUS FOR OUTLAY)
INPUT IN DOLLARS ONLY(E.G. -1000,3000)


YEAR    1
=-7720,0
YEAR    2
=-5224,14740
YEAR    3
=-9495,14740
YEAR    4
=-10112,14740
YEAR    5
=-12523,14740
YEAR    6
=-11915,14740
YEAR    7
=-10042,14740
YEAR    8
=-9701,14740
YEAR    9
=-12579,14740
YEAR   10
=-10018,14740
YEAR   11
=-442,14740
YEAR   12
=-7074,0
```

Figure E (continued)

INPUT DATA SUMMARY

YEAR	OUTLAY O	INCOME I	INTEREST X
0	-15735.00	0.	0.
1	-7720.00	0.	0.
2	-5224.00	14740.00	0.
3	-9495.00	14740.00	0.
4	-10112.00	14740.00	0.
5	-12523.00	14740.00	0.
6	-11915.00	14740.00	0.
7	-10042.00	14740.00	0.
8	-9701.00	14740.00	0.
9	-12579.00	14740.00	0.
10	-10018.00	14740.00	0.
11	-442.00	14740.00	0.
12	-7074.00	0.	0.

IS DATA CORRECT 1=YES 2=NO
=1

YEAR	NET CASH FLOW O+I+X	CUMULATIVE FLOW END OF PERIOD
0	-15735.00	-15735.00
1	-7720.00	-23455.00
2	9516.00	-13939.00
3	5245.00	-8694.00
4	4628.00	-4066.00
5	2217.00	-1849.00
6	2825.00	976.00
7	4698.00	5674.00
8	5039.00	10713.00
9	2161.00	12874.00
10	4722.00	17596.00
11	14298.00	31894.00
12	-7074.00	24820.00

PAYBACK OF INI. INV. IS 5 YEARS 2 MONTHS

YEAR	OPERATING CASH FLOW O+I	PRESENT VALUE OF OPERATING CASH FLOW
1	-7720.00	-6705.68
2	9516.00	7179.68
3	5245.00	3437.33
4	4628.00	2634.48
5	2217.00	1096.21
6	2825.00	1213.31
7	4698.00	1752.63
8	5039.00	1632.85
9	2161.00	608.25
10	4722.00	1154.46
11	14298.00	3036.36
12	-7074.00	-1304.87

CUMULATIVE PRESENT VALUE OF CASH FLOWS 15735.00

RATE OF RETURN EQUATING P.V. OF FLOW TO ZERO IS 15.1[illegible] %

BIBLIOGRAPHY

AGIUS, C, JACCARINI, V and RITZ, D A (1978). Growth Trials of *Crassostrea gigas* and *Ostrea edulis* in Inshore Waters of Malta.
Aquaculture Vol. 15, No. 3, p. 195-218.

AGNELLO, R J and DONNELLEY, L P (1975). The Interaction of Economic, Biological and Legal Forces in the Middle Atlantic Oyster Industry.
U S Department of Commerce Natl. Mar. Fish. Ser. Fishery Bulletin, Vol. 73(2), part 2, p. 256-261.

ALDERMAN, D J (1969). Shell Disease of *Ostrea edulis* L.
PhD thesis, University of London.

ALDERMAN, D J (1974). Foreign Disease Hazard to British Shellfish.
New Scientist, Vol. 63, p. 122-124.

ALLEN, P G and JOHNSTON, W E (1976). Research direction and economic feasibility: An example of system analysis for lobster culture.
Aquaculture, Vol. 9, No. 2, p. 155-180, October 1976.

ANDERSON, L G (1980). Necessary components of Economic surplus in Fisheries Economics.
J. Fish. Res. Bul. Can., Vol. 37, No. 5, p. 858-870, May 1980.

ANON (1974) Hatchery for Seed Oysters in North Wales
Fish. Farm. Int. No. 3, p. 118-121.

ANON (1978). Keepability of Damaged Mussels.
Fish. Farm. Int. Vol. 5, No. 3, p. 30-33.

ANON (1979a). Oyster Sales Breakthrough.
Fish. Farm. Int. Vol. 6, No. 4, p. 7, 1976.

ANON (1979b). Growing Demand for Bulk Supplies.
Fish Farmer, Vol. 2, No. 4, p. 36, 1979.

ANON (1979c). French Test Clam Culture in Oyster Beds.
Fish. Farm. Int. Vol. 6, No. 4, p. 14-16, 1979.

ANON (1980a). The Billingsgate Column.
Fishing News, 29 February 1980, p. 17.

ANON (1980b). Import of Lobsters from Canada.
Fishing News, 19 September 1980, p. 4.

ANON (1980c). South Wales Introduces Licences for Lobster and Crab Fishing.
Fishing News, 18 April 1980, p. 17.

ANON (1980d). Culture Could Keep Lobster on the Menu.
Fish Farmer, Vol. 3, No. 4, p. 28-30, 1980.

ANON (1980e). Mussels in Britain.
Fish. Farm. Int. Vol. 7, No. 4, p. 22-23, 1980.

ANON (1980f). Harvesting Mussels in Brittany.
Fishing News, 4 April 1980, p. 17.

ANON (1981) Shellfish Culture in Scotland.
Fish Farmer, Vol. 4, No. 4, p. 6-7, 1981.

ANSELL, A D (1963). *Venus mercenaria* (L) in Southampton Water.
Ecology, Vol. 44, p. 396-397.

ANTHONY, R N and REECE, J S (1975). Management Accounting:
Text and Cases
ISBN 0 256 01648 8, 1975, 830p; Richard Irwin Inc.

ASKEW, C G (1972). The Growth of Oysters *Ostrea edulis* and *Crassostrea gigas* in Emsworth Harbour.
Aquaculture, Vol. 1, No. 3, p. 237-259, December 1972.

ASKEW, C G (1976). Biological Assessment of Offbottom Culture of Oysters in British Waters, including a consideration of Economic Implications.
PhD thesis, Portsmouth Polytechnic, 1976.

ASKEW, C G (1978). A Generalised Growth and Mortality Model for Assessing the Economics of Bivalve Culture.
Aquaculture, Vol. 14, No. 2, p. 91-104, June 1978.

AYRES, P A (1978). Shellfish Purification in Installations using Ultraviolet Light.
MAFF Lab. Leaflet, No. 43, 22pp, Lowestoft 1978,
ISBN 0072 6699.

AYRES, P A and CULLUM, M (1978). Paralytic Shellfish Poisoning: An Account of Investigations into Mussel Toxicity in England 1968 - 1977.
MAFF Fish. Res. Tech. Rep. No. 44, 23pp, 1978.

BERGE, L (1976). A Proposal for Economic Investigations of Fish Farms with Special Reference to Book keeping and Financial Analysis.
FAO Tech. Conf. Aquaculture, Kyoto, Japan 26 May - 2 June 1976. FIR AQ/CONF/76/E80 p. 239-246.

BEVERTON, R J H and HOLT, S J (1957). On the Dynamics of Exploited Fish Populations.
Fishery Invest. London, Ser. 2(19), 533pp.

BRIGGS, R P (1978). Aspects of Oyster Cultivation in Strangford Lough, Northern Ireland.
Aquaculture, Vol. 15, No. 4, p. 307-318, December 1978.

COLE, H A (1940). Effects of the Severe Winter of 1939-40 on the British Oyster Beds.
Nature, London, Vol. 145, p. 976.

COLE, H A (1956). Oyster Cultivation in Britain: A Manual of Current Practice.
HMSO, London, 43pp, 1956.

CURR, C T W (1974). Two Applications of Mathematical Programming in Fisheries Research and Development.
Northern O R Conference, York, April 1974, 15pp.

CUSHING, D H (1975). Marine Ecology and Fisheries.
Cambridge University Press, 278pp, 1975, ISBN 0 521 09911 0.

DARBYSHIRE, M and DRAPER, L (1963). Forecasting Wind Generated Sea Waves.
Engineering, Vol. 195, p. 482-484, April 1963.

DARE, P J (1977). Damage Caused to Mussels (*Mytilus edulis*) caused by Dropping During Handling Operations.
MAFF, Fish. Res. Tech. Rep. No. 34, 6pp, 1977.

DAVIDSON, P E (1974). Cultivating Pacific Oysters in the United Kingdom.
Fish. Farm. Int., No. 3, p. 58-64, 1974.

DAVIDSON, P E (1976). Oyster Fisheries of England and Wales.
MAFF, Lab. Leaflet, No. 31, 16pp, 1976.

DAVIES, R (1979). Pacific Oyster Producer goes for Expansion as seaside sales take off.
Fish Farmer, Vol. 2, No. 5, p. 34-36, July 1979.

DRUDY, P J and WALLACE, D B (1971). Towards a Development Programme for Remote Rural Areas: A Case Study in North Norfolk.
Regional Studies, Vol. 5, No. 4, p. 281-288, 1971.

EPIFANIO, C E (1979). Growth in Bivalve Molluscs: Nutritional Effects of Two or more species of Algae in Diets Fed to the American Oyster, *Crassostrea virginica* (Gmelin) and the Hard Clam, *Mercenaria mercenaria*.
Aquaculture, Vol. 18, No. 1, p. 1-12, 1979.

FAO (1980). Yearbook of Fishery Statistics: Catches and Landings 1979.
FAO Rome, Vol. 48, 384pp, ISBN 92 5 001031 0.

FORBES, J (1969). A Map Analysis of Potentially Developable Land.
Regional Studies, Vol. 3, No. 2, p. 179-195, September 1969.

FRANKLIN, A; PICKETT, G D and CONNOR, P M (1980). The Scallop and its Fisheries in England and Wales.
MAFF, Lab. Leaflet No. 51, 19pp, 1980. ISBN 0143 8018.

FULTON, T W (1896). The Past and Present Condition of the Oyster Beds in the Firth of Forth.
Rep. Fish. Bd. Scot. (1895), 14(3): p. 244-293.

GAGE, J (1974). Shallow Water Zonation of Sea Loch Benthos and its Relation to Hydrographic and other Physical Features.
J. Mar. Biol. Assoc. U.K., 54: p. 223-249.

GARDNER, G A A (1973). Shellfish Farming Progress.
WFA, Fish. Ind. Rev., Vol. 3, part 3, p. 2-4.

GROSS, F and SMYTH, J C (1946). The Decline of Oyster Populations.
Nature, London, Vol. 157, p. 540-542, 1946.

GULLARD, J A (1969). Manual of Methods of Fish Stock Assessment: Part I, Fish Population Analysis.
FAO, Manuals in Fisheries Science, No. 4, 154pp, 1969.

HAILS, A J (1978). The Application of a Simple Economic Technique to Fisheries Management Problems.
Fish. Management, Vol. 9, No. 2, p. 39-44, May 1978.

HAMMOND, D E and LACKEY, R T (1976). Analysis of Catchable Trout Fisheries Management by Computer Simulation.
Trans. Amer. Fish. Soc., Vol. 105, No. 1, p. 48-56, January 1976.

HANCOCK, D A (1974). Oyster Pests and their Control.
MAFF, Lab. Leaflet, No. 19, 30pp, November 1974.

HAWKINS, C J and PEARCE, D W (1971). Capital Investment Appraisal.
Macmillan Studies in Economics, 1971. ISBN 333 11866 9.

HAYWOOD, K H and CURR, C T W (1970). An Operational Research Study into the Economics of Seed Mollusc Production.
Shellfish Assoc. of G.B. Conference, London, 6-7 April 1970, 14pp.

HELM, M M; LAING, I and JONES, E (1979). The Development of a 200 litre Algal Culture Vessel at Conwy. MAFF, Fish. Res. Tech. Paper No. 53, 18pp, 1979.

HONEYWELL, (1973). Series 60/(Level 66)/6000. Time sharing Applications Library Guide. Vol. IV, Business and Finance, 137pp, June 1973.

HUANG, W; WANG, J and FUJIMURA, T (1976). A Model for Estimating Prawn Populations in Ponds. Aquaculture, Vol. 8, No. 1, p. 57-70, 1976.

HUGUENIN, J E and AUSUINI, F J (1978). A Review of the Technology and Economics of Marine Fish Cage Systems. Aquaculture, Vol. 15, No. 2, p. 151-170, October 1978.

JOHNSTON, R S and NELSON SWARTZ, A (1976). The Demand for Pacific Oysters: A preliminary report. Proc. Nat. Shellfish Assoc., Vol. 67, p. 127-128, 1976.

JORGENSEN, C B (1976). August Putter, August Krough and Modern Idease on the Use of Dissolved Organic Matter in Aqueous Environments. Biol. Rev., Vol. 51, No. 3, p. 291-328, August 1976.

KERR, N M and HAYWOOD, K T (1975). The Potential for Marine Cultivation in the United Kingdom. Jour. Roy. Soc. of Arts, No. 5232, Nov. 1975.

KEY, D (1969). Methods of Cultivating Small Oysters. MAFF, Shellfish Info. Bull. No. 14, April 1969.

KEY, D (1970). Further Results from Experiments on the Culture of Small Oysters. MAFF, Shellfish Info. Bull. No. 17, March 1970.

KEY, D (1972). The Stanswood Bay Oyster Fishery. MAFF, Shellfish Info. Leaflet No. 25, August 1972.

KEY, D (1974). A Survey of Oyster grounds in the Solent in 1973. MAFF, Shellfish Info. Leaflet No. 31, February 1974.

KEY, D and NUNNY, R S (1976). Ongrowing of Hatchery Reared Oyster Spat. MAFF, Occasional Paper, May 1976.

KEY, D (1977a). Natural Stocks of Oysters on Public Grounds in the Solent and Adjoining Harbours in 1976. MAFF, Fisheries Notice No. 50, 18pp, 1977. ISSN 0436 4430.

KEY, D (1977b). Deposit of Molluscan Shellfish.
MAFF, Lab. Leaflet, No. 34, 10pp, 1977. ISSN 0072 6699.

KEY, D and DAVIDSON, P E (1981). A Review of Development of the Solent Oyster Fishery 1972-80.
MAFF, Lab. Leaflet, No. 52, 36pp, 1981. ISSN 0143 8018.

KING, C A M (1972). Beaches and Coasts.
Edward Arnold, London, 570pp, 1972. ISBN 7131 5609 0.

KING, M G (1977). Culture of the Pacific Oyster *(Crassostrea gigas)* in non tidal Hypersaline Ponds.
Aquaculture, Vol. 11, No. 2, p. 123-136, 1977.

KINNE, O (1976). Marine Ecology.
Wiley Interscience, Vol. III Cultivation: Part 3, ISBN 0 471 4800.

KIRK, R G (1979). Marine Fish and Shellfish Culture in the Member States of the EEC.
Aquaculture, Vol. 16, No. 2, p. 95-122, 1979.

KORRINGA, P (1976). Farming the Cupped Oyster of the Genus Crassostrea: A Multidisciplinary Treatise.
Elsevier Scientific Pub. Co. 224pp, 1976. ISBN 0444 413332.

LANDLESS, P J and EDWARDS, A (1976). Economic Ways of Assessing Hydrography for Fish Farms.
Aquaculture, Vol. 8, No. 1, p. 29-43, 1976.

LANGTON, R W and GABBOTT, P A (1974). The Tidal Rhythm of Extracellular Digestion and the Response to Feeding in *Ostrea edulis* (L).
Mar. Biol. Vol. 24, p. 181-187, 1974.

LAWTON, R (1968). The Journey to Work in Britain: Some Trends and Problems.
Regional Studies, Vol. 2, p. 27-40.

LEWIS, M R (1979). Fish Farming in Great Britain - An Economic Survey with Special Reference to Rainbow Trout.
Univ. Reading Dept. Agric. Econ. Misc. Studies No. 67, 74pp, 1979.

LEY, C (1979). Loch to Produce 600,000 Oysters per Year.
Fish Farmer, Vol. 2, No. 4, p. 37, May 1979.

LUCAS, A (1976). Aspects of the Rearing and Cultivation of *Venerupis*.
Shellfish Assoc. of G.B. Conference 18-19 May 1976, p. 32-36.

LUTZ, R A and HESS, R T (1979). Biological and Radiological Analysis of the Potential of Nuclear Power Plant Effluent Water for Shellfish Culture.
in Power Plant Waste Heat Utilisation in Aquaculture, ed. B Godfriaux, p. 109-138, ISBN 0 916672 24 7.

McANUFF, J W (1979). Towards a Strategy for Fish Farming in the United Kingdom.
Food Policy, Vol. 4, Part 3, p. 178-193, 1979.

McANNUFF, J W (1980). Britain Catches onto Fish Farming
New Scientist, Vol. 85, No. 1199, p. 915-917, 1980.

MacFARLANE, I S and VARLEY, R L (1976). Risk, Mortality and Insurance of European Trout Farms.
in Advances in Aquaculture, p. 70-74. Fishing News Books Ltd, ISBN 0 85238 092 5.

McKELLAR, N B (1971). The Outlook for Scottish Shellfish.
Fish Industry Review, Vol. 1, No. 3, p. 2-5, 1971.

MacSWEEN, I (1980). An Industry in Crisis.
Fishing News, p. 11-13, 26 September 1980.

MACKIN, J G; KORRINGA, P and HOPKINS, S H (1952). Hexamitiasis of *O. edulis* and *C. gigas* (Gmelin).
Bull. Mar. Sci. Gulf. Carib. Vol. 1, p. 266-273.

MADDOCK, L and SWANN, C L (1977). A Statistical Analysis of Some Trends in the Sea Temperature and Climate in the Plymouth Area in the Last 70 Years.
J. Mar. Biol. Assoc., Vol. 57, p. 317-338, 1977.

MAFF (1973). The Impact of Mechanical Harvesting on the Thames Estuary Cockle Fishery.
MAFF Lab. Leaflet No. 29, 15pp, 1973.

MAFF (1980). Household Food Consumption and Expenditure: 1979. Annual Report of the National Food Survey Committee, 1980, 218pp, HMSO ISBN 011 241167 3.

MALOUF, R E and BREESE, W P (1977). Seasonal Changes in the Effects of Temperature and Water Flow Rate on the Growth of Juvenile Pacific Oysters (*Crassostrea gigas*).
Aquaculture, Vol. 12, No. 1, p. 1-13, 1977.

MARASCO, R (1974). Food from the Sea: An Economic Perspective of the Seafood Market.
American Jour. Agric. Econ., Vol. 56, No. 5, p. 1030-1037, December 1974.

MASON, J (1972). The Cultivation of the European Mussel *Mytilus edulis*.
Oceanogr. Mar. Biol., Annual Review No. 10, p. 437-460.

MASON, J (1980). Scottish Shellfish - A £20m Catch.
Fishing News, 20 June 1980, p. 60-67.

MAYER, A C and MAYER, D G (1976). Introductory Economic Statistics.
Wiley & Sons, 223pp, 1976. ISBN 0 471 581119.

MELHUISH, M (1980). Scalloping Methods and Gear.
Fishing News, 24 October 1980, p. 24-29.

MILLAR, R H (1961). Scottish Oyster Investigations: 1946 - 1958.
DAFS, Mar. Res. No. 3, 76pp, 1961.

MILLAR, R J (1968). Changes in the Population of Oysters in Loch Ryan between 1957 and 1967.
DAFS, Mar. Res. Ser. No. 1, 12pp, 1968. SBN 11 49004 3.

MILLAR, M M and NASH, D A (1974). Regional and Other Related Aspects of Shellfish Consumption - Some Preliminary Findings from the 1969 Consumer Panel Survey.
Nat. Mar. Fish. Ser. US, Circular No. 31, 14pp, 1974.

MORTON, B S (1971). The Diurnal Rhythm and Tidal Rhythm of Feeding and Digestion in *Ostrea edulis*.
Biol. Journ. Linn. Soc., 3,(4), p. 329-342, 1971.

MORTON, B S (1977). The Tidal Rhythm of Feeding and Digestion in the Pacific Oyster *Crassostrea gigas* (Thunberg).
J. Exp. Mar. Biol. Ecol. 26(2), p. 135-151.

MURRAY, J and BURT, J R (1969). The Composition of Fish.
MAFF Torry Advisory Note No. 38, 16pp, 1969.

NEEDHAM, E (1979). Time for a New Political Initiative.
Fish Farmer, Vol. 3, No. 1, p. 8-9, 1979.

NEWBY, H (1977). The Deferential Worker. A Study of Farm Workers in East Anglia.
Allan Lane, 462pp, 1977. ISBN 0 7139 0892 0.

NIX, J (1978). Farm Management Pocketbook.
Wye College, University London, 156pp, 9th Edition, 1978.

NORTON, M G (1976). The Operation of the Dumping at Sea Act 1974.
Chemistry and Industry, 2 October 1976, p. 829-834.

O'BRIEN, F I (1979). Market time prediction during raft culture of oysters.
Fish. Farm Int. Vol. 6, No. 4, p. 12-13, December 1979.

O'FARRELL, P N and MARKHAM, J (1975). The Journey to work: a behavioural analysis.
Progress in Planning, Vol. 3, Part 3, 288pp.

O'SULLIVAN, B W and WILSON, J H (1976). Development of an Experimental Oyster Hatchery.
Fish. Farm. Int. Vol. 3, No. 3, p. 12-15, 1976.

PARKER, R G B (1979). Fish Farming in Europe.
Food Policy, Vol. 4, No. 3, p. 194-203, 1979.

PARSONS, J (1971). Preliminary Notes on the Cultivation of the Pacific Oyster (*Crassostrea gigas*) in Northern Ireland.
MANI, Fish. Lab. Leaflet No. 2, 16pp, 1971.

PARSONS, J (1972). Growth Rate and Mortality of Hatchery-reared Pacific Oysters (*Crassostrea gigas*) in Strangford Lough, Northern Ireland.
Cons. Perm. Int. Explor. mer. C.M. 1972/K32, 12pp.

PARSONS, J (1974). Advantages in Tray Cultivation of Pacific Oysters (*C. gigas*) in Strangford Lough, Northern Ireland.
Aquaculture, Vol. 3, No. 3, p. 221-229, 1974.

PHILIPS, A A C (1973). Development and Conservation: The Coastal Context.
Town and Country Planning, July - August 1973, p. 359-362.

PICKETT, G (1979). Scientists Pave the Way for British Scallop Industries.
Fish Farmer, Vol. 2, No. 2, p. 33-34, 1979.

PULLIN, R S V (1977). Coastal Aquaculture in Europe.
Marine Policy Vol. 1, p. 205-214, July 1977.

PURDOM, C E (1979). Fish Farming in the United Kingdom.
Biologist, Vol. 26, No. 4, p. 153-157, 1979.

QUAYLE, D B (1969). Pacific Oyster Culture in British Columbia.
Fish. Res. Bd. Can., Bulletin No. 169, 192pp, 1969.

RAUCH, H E; BOTSFORD, L W and SHLESER, R A (1975). Economic Optimisation of an Aquaculture Facility.
IEEE Trans. Autom. Control USA, Vol. AC 20, p. 310-319. 1975.

RICKER, W E (1968). Handbook of Computations for Biological Statistics of Fish Populations.
Fish. Res. Bd. Can., Bulletin No. 119, 300 pp, 1968.

RICKER, W E (1973). Linear Regression in Fisheries Research.
J. Fish. Res. Bd. Can., Vol. 30, No. 3, p. 409-434.

RYTHER, J T (1969). The Potential of the Estuary for Shellfish Production.
Proc. Nat. Shellfish Assoc. Vol. 59, p. 18-22, 1969.

SECRETAN, P A D (1979). Beware the Natural Catastrophe.
Fish. Farm. Int. Vol. 5, No. 5, p. 28, 1979.

SEDGWICK, S D (1978). Beware of False Experts.
Fish Farmer Vol. 2, No. 1, p. 4, 1978.

SEPHTON, J R D (1980). The Scottish Periwinkle Fishery.
Occasional Report, TERU, University of Stirling, 198pp, 1980.

SHELDON, R W (1968). The Effect of High Population Densities on the Growth and Mortality of Oysters, *Ostrea edulis*.
J. Cons. Perm. Int. Explor. mer., Vol. 31, No. 3, p. 352-363, 1968.

SHEPHERD, C J (1973). Studies on the Biological and Economic Factors Involved in Fish Culture, with Special Reference to Scotland.
Unpublished PhD thesis, University of Stirling, 1973.

SLATER, J (1979). Search for Bulk Supplies on Scotland's West Coast.
Fish Farmer Vol. 2, No. 2, p. 33-35, 1979.

SPENCER, B E (1978). A Costing of Large Scale Tray Cultivation of Hatchery-reared Seed of *Crassostrea gigas* at Tal y foel, 1978.
MAFF Conwy, Internal Report, 4pp, 1978.

SPENCER, B E and GOUGH, C J (1978). The Growth and Survival of Experimental Batches of Hatchery-reared Spat of *Ostrea Edulis* and *Crassostrea gigas* using Different Methods of Tray Cultivation.
Aquaculture, Vol. 13, No. 4, p. 293- 2, 1978.

SPENCER, B E; KEY, D; MILLICAN, P F and THOMAS, M J (1978). The Effect of Intertidal Exposure on the Growth and Survival of Hatchery-reared Pacific Oysters (*Crassostrea gigas*) kept in Trays During their First Ongrowing Season.
Aquaculture, Vol. 13, No. 3, p. 191-204, 1978.

RAUCH, H E; BOTSFORD, L W and SHLESER, R A (1975). Economic Optimisation of an Aquaculture Facility. IEEE Trans. Autom. Control USA, Vol. AC 20, p. 310-319. 1975.

RICKER, W E (1968). Handbook of Computations for Biological Statistics of Fish Populations. Fish. Res. Bd. Can., Bulletin No. 119, 300 pp, 1968.

RICKER, W E (1973). Linear Regression in Fisheries Research. J. Fish. Res. Bd. Can., Vol. 30, No. 3, p. 409-434.

RYTHER, J T (1969). The Potential of the Estuary for Shellfish Production. Proc. Nat. Shellfish Assoc. Vol. 59, p. 18-22, 1969.

SECRETAN, P A D (1979). Beware the Natural Catastrophe. Fish. Farm. Int. Vol. 5, No. 5, p. 28, 1979.

SEDGWICK, S D (1978). Beware of False Experts. Fish Farmer Vol. 2, No. 1, p. 4, 1978.

SEPHTON, J R D (1980). The Scottish Periwinkle Fishery. Occasional Report, TERU, University of Stirling, 198pp, 1980.

SHELDON, R W (1968). The Effect of High Population Densities on the Growth and Mortality of Oysters, *Ostrea edulis*. J. Cons. Perm. Int. Explor. mer., Vol. 31, No. 3, p. 352-363, 1968.

SHEPHERD, C J (1973). Studies on the Biological and Economic Factors Involved in Fish Culture, with Special Reference to Scotland. Unpublished PhD thesis, University of Stirling, 1973.

SLATER, J (1979). Search for Bulk Supplies on Scotland's West Coast. Fish Farmer Vol. 2, No. 2, p. 33-35, 1979.

SPENCER, B E (1978). A Costing of Large Scale Tray Cultivation of Hatchery-reared Seed of *Crassostrea gigas* at Tal y foel, 1978. MAFF Conwy, Internal Report, 4pp, 1978.

SPENCER, B E and GOUGH, C J (1978). The Growth and Survival of Experimental Batches of Hatchery-reared Spat of *Ostrea Edulis* and *Crassostrea gigas* using Different Methods of Tray Cultivation. Aquaculture, Vol. 13, No. 4, p. 293- 2, 1978.

SPENCER, B E; KEY, D; MILLICAN, P F and THOMAS, M J (1978). The Effect of Intertidal Exposure on the Growth and Survival of Hatchery-reared Pacific Oysters (*Crassostrea gigas*) kept in Trays During their First Ongrowing Season. Aquaculture, Vol. 13, No. 3, p. 191-204, 1978.

TENORE, K R and DUNSTON, W M (1973). Comparison of Feeding and Biodeposition of Three Bivalves at Different Food Levels. Marine Biology, Vol. 21, p. 190-195, 1973.

THOMAS, H J (1970). The Norway Lobster. DAFS, Scottish Fisheries Info. Pamphlet, 16pp, 1970.

TRAPPER (1979). Shellfish Chat Column. Fishing News, 16 March 1979, p. 17.

TRAPPER (1980). Shellfish Chat Column. Fishing News, 29 August 1980, p. 6.

URCH, M (1976). Market Tests of a Range of Oyster Products. WFA, Tech. Rep. No. 138, 65pp, 1976.

VARLEY, R L (1977). Economics of Fish Farming in the United Kingdom. Fish. Farm. Int. Vol. 4, No. 1, p. 17-19, 1977.

WALNE, P R (1958). Growth of Oysters (*Ostrea edulis*, L). J. Mar. Biol. Assoc. UK, Vol. 37, p. 591-602, 1958.

WALNE, P R (1961). Observations on the Mortality of *Ostrea edulis*. J. Mar. Biol. Assoc. UK, Vol. 41, p. 133-122, 1961.

WALNE, P R and DEAN, G J (1967). Studies on the Introduction of the American Clam (*Mercenaria mercenaria*) into British Waters. ICES, CM 1967/E:6, 7pp (mimeo).

WALNE, P R (1970a). Present Problems in the Culture of the Larvae of *Ostrea edulis*. Helgolander wiss. Meeresunters, Vol. 20, p. 514-525.

WALNE, P R (1970b). The Seasonal Variation of Meat and Glycogen Content of Seven Populations of Oysters, *Ostrea edulis*, L. and a Review of the Literature. MAFF, Fish. Invest. Ser. 2, Vol. 26, No. 3, 35pp.

WALNE, P R (1971). A Comparison of Seasonal Growth of Five Species of Bivalves in the Menai Straits. Int. Council Explor. Sea, Shellfish and Bethos Committee Vol. CM 1971/K12, 5pp, 1971.

WALNE, P R and SPENCER, B E (1971). The Introduction of the Pacific Oyster (*Crassostrea gigas*) into the United Kingdom. MAFF, Shellfish Info. Leaflet No. 21, 14pp, 1971.

WALNE, P R (1972). The Importance of Estuaries to Commercial Fisheries. in The Esturine Environment. Chapter 7, p. 107-118, eds Barnes, R S K and Green J. ISBN 0 85334 539 2.

WALNE, P R and WOOD, P C (1973). A Review of Some of the Shellfish Research Undertaken at the Fisheries Laboratory in 1972. MAFF, Shellfish Info. Leaflet No. 30, 54pp, 1973.

WALNE, P R (1974). Culture of Bivalve Molluscs: 50 Years Experience at Conwy. Fishing News (Books) Ltd. 173pp, 1974. ISBN 0 85238 063 1.

WALNE, P R and SPENCER, B E (1974). Experiments on the Growth and Food Conversion Efficiency of the Spat of *Ostrea edulis*, L. in a Recirculation System. J. Cons. Int. Explor. mer. Vol. 35, No. 3, p. 303-318.

WALNE, P R (1975). The Growth of *Ostrea edulis* in the Menai Straits. Proc. Challanger Soc. Vol. IV, part 6, p. 272.

WALNE, P R and MANN, R (1975). Growth and Biochemical Composition in *Ostrea edulis* and *Crassostrea gigas*. Proc. 9th European Mar. Biol. Symp. pp. 587-607, Aberdeen University Press, 1975.

WALNE, P R (1976). Experiments on the Culture in the Sea of the Butterfish *Venerupis decussata* L. Aquaculture, Vol. 8, No. 4, p. 371-381, 1976.

WALNE, P R (1977). Protection of Young Mussels and Oysters by Fences. MAFF, Fisheries Notice No. 53, 10pp, 1977.

WALNE, P R and HELM, M M (1979). The Introduction of *Crassostrea gigas* into the United Kingdom. in Exotic Species in Mariculture, ed. R Mann, p. 83-105, 1979. ISBN 0 262 13155 2.

WATERMAN, J J (1964). Measures, Storage rates and Yields of Fishery Products. MAFF, Torry Advisory Note No. 17, 12pp, 1964.

WESTBROOK, L (1978). Handling Dutch Mussels. Fish. Farm. Int. Vol. 5, No. 3, p. 30-33, September 1978.

WFA (1974). Specifications for the Freezing and Packaging of Oyster Meat and Oyster Products. WFA, Technical Report No. 104, 41pp, February 1974.

WFA (1975). The Overwintering of *Crassostrea gigas* Seed at Eight Locations around the United Kingdom. WFA, Technical Report No. 120, 21pp, 1975.

WFA (1975). Factors influencing the Choice of any Proposed Coastal Marine Fish Cultivation Site and Recommended Survey Programme. WFA, Technical Report No. 118, 10pp, 1975.

WFA (1976). A Manual of Standard Procedure and Equipment Specification for a Seed Oyster Hatchery. WFA, Shellfish Cultivation Report, 108pp, February 1976,

WHEATON, F W (1971). Engineering Approach to Oyster Processing. Trans. Amer. Soc. Agric. Engin., Vol. 14, part 1, p. 187-192, 1971.

WHEATON, F W (1974). Design Constraints on an Oyster Shucking Machine. Proc. Natl. Shellfish Assoc. Vol. 64, p. 118-121, 1974.

WHITEHEAD, C; BROMAGE, N; LINDFIELD, G and FORESTER, J (1980). Table Fish Move into the Computer Age. Fish Farmer Vol. 3, No. 2, p. 14-16, 1980.

WICKEN, J F and BEARD, T W (1978). Prawn Culture Research. MAFF, Lab. Leaflet No. 42, 41pp, 1978. ISSN 0072 6699.

WIDDOWS, J and BAYNE, B L (1971). Temperature Acclimation of *Mytilus edulis* with reference to its Energy Budget. J. Mar. Biol. Assoc. UK, Vol. 51, p. 827-84^, 1971.

WILBUR, K M and OWEN, G (1964). Physiology of Mollusca. Academic Press, Vol. 1, 473pp, 1964.

WOOD, P C (1969). The Production of Clean Shellfish. MAFF, Lab.Leaflet No. 20, 16pp, 1969.

WOOD, P C (1972). The Principles and Methods Employed for the Sanitory Control of Molluscan Shellfish. in Marine Pollution and Sea Life, ed. M Ruivo, p. 560-565, 1972. ISBN 0 85238 021 6.

WOOD, P C (1976). Guide to Shellfish Hygiene. WHO, Offset Publ. No. 31, 1976. ISBN 924 170031 9.

WOOD, P C and AYRES, P A (1977). Artificial Seawater for Shellfish Tanks. MAFF, Lab. Leaflet No. 39, 12pp, 1977.

YELF, J D (1978). An Oyster for All Seasons. Fish. Farm. Int. Vol. 5, No. 1, p. 28-29, 1978.

YEOMAN, K A (1968). Statistics for the Social Scientist: 2 Applied Statistics. Penguin Educational Ltd, 397pp, 1968. ISBN 0 14 08 0006 9.

YONGE, C M (1960). Oysters.
Collins, New Naturalist Series, Special Vol. No. 18, 209pp, 1960.

YONGE, C M (1970). Oyster Culture.
Underwater Sci. and Tech. Jour. Vol. 13, part 2, p. 138-144, 1970.