Thesis
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ASSESSING SUSTAINABILITY OF AQUACULTURE DEVELOPMENT

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Thesis submitted for the degree of PhD

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March 1995

DECLARATION

I declare that this thesis has been composed by myself and that it embodies the results of my own research. Where appropriate I have acknowledged the nature and extent of work carried out in collaboration with others.

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26/05/95

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ABSTRACT

Aquaculture, as an aquatic based economic activity, has risen from relative obscurity to a position of global recognition in just over two decades, and is forecast to become increasingly important in the next century. This growth, however, has been accompanied by increasing concerns over the environmental and social costs associated with the exploitation of the natural resource base on which it depends. This occurs in the broader context of increasing awareness of the finite capacity of the global system, and the need for development of more sustainable resource management regimes. The objective of the study is to examine if and how 'sustainability' can be brought into assessment for aquaculture development.

The main concepts of sustainability are discussed, and key issues for assessment identified. The range of impacts associated with aquaculture development is reviewed, and broad categories of sectoral sustainability indicators proposed. Specific issues and assessment approaches are examined in three case studies, focusing on environment interactions, resource use assessment, and the rural development context, respectively. There follows a structured analysis of applicability of selected generic appraisal methods, concluding that while all may contribute, none is sufficiently broad to account for all sustainability perspectives. A more comprehensive framework for the assessment is therefore proposed, by which sustainability features of any system can be described, potential indicators and methods of assessment identified, and results communicated to the decision making process. This does not offer a definitive judgement on sustainability, but presents an holistic view, allowing explicit recognition of trade-offs involved between conflicting sustainability objectives. It is concluded that sufficient information is available for this approach to be developed and applied on a wider basis. Constraints to more sustainable development relate more to the social, political and economic environment than to problems of uncertainty in forecasting biological and physical systems.

ACKNOWLEDGEMENTS

As a part time study, this work took many more years to complete than I had ever intended. While the writing is a relatively solitary activity, the exercise required the help, cooperation and support of many people, in many ways - related to both the content of the thesis, and to the circumstances of its production. Without going into the details, I would like to extend my thanks to:

Dr James F Muir
Dr John F Dalrymple
Professor R.J.Roberts
Malcolm Beveridge
Donald Baird
Helen Carroll
Staff and management of Rothesay Sea Foods Ltd.
Staff in the Department of Management Science

I would also like to thank others at the Institute of Aquaculture, friends and family... indeed all those who learned not to ask, too often... "how is the PhD going?"

ASSESSING SUSTAINABILITY OF AQUACULTURE DEVELOPMENT

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ACRONYMS and ABBREVIATIONS

Terminology

CC Cultural Capital
GDP Gross Domestic Produce
GNP Gross National Produce
HMC Human made Capital
LDC Less Developed Country
NC Natural Capital
NNC Non renewable Natural Capital
RNC Renewable Natural Capital
TCO Technical Cooperation officer
TOR Terms Of Reference
VSO Voluntary Service Overseas

Analytical methods/ terminology

CBA Cost Benefit Analysis
CEA Cost Effectiveness Analysis

EA Energy Analysis
ECCO Enhanced Carrying Capacity Options
EFA Ecological Footprint Analysis
EIA Environmental impact Assessment
EIS Environmental Impact Statement
FSR&D Farming Systems Research and Development
GER Gross Energy Requirement
GIS Geographic Information Systems
IEA Industrial Energy Analysis
IRMP Integrated Resource Management Planning
IRR Internal Rate of Return
LCA Life Cycle Assessment
MCA Multi-Criteria Analysis
NPV Net Present Value
PA Participatory Appraisal
PRA Participatory Rural Appraisal
ROI Return on Investment
RRA Rapid Rural Appraisal
SCBA Social Cost Benefit Analysis
SIA Social Impact Assessment

Fish farming and environmental quality measures

BKD Bacterial Kidney Disease
BOD Biological Oxygen Demand
Chl 'a' Chlorophyll 'a'
DO Dissolved Oxygen
DP Dissolved Phosphorous
ERM Enteric Redmouth Disease
FCR Food Conversion Rate
P Phosphorus
PKD Proliferative Kidney Disease
SGR Specific Growth Rate

Organisations

DoF Department of Fisheries
EC European Community
EPA Environmental Protection agency
FAO United Nations Food and Agricultural Organisation
GoM Government of Malawi
HIDB Highlands and Islands Development Board
LGMB Local Government Management Board
ODA United Kingdom Overseas Development Administration

IUCN International Union for the Conservation of Nature
OECD Organisation for Economic Cooperation and Development
UNCED United Nations Conference on Environment and Development (1992)
WCED World Commission on Environment and Development

SECTION 1

INTRODUCTION

SECTION 1 INTRODUCTION

Chapter 1 Context and approach

1.1 Background

A widely used, perhaps cliched proverb has been invoked to explain fishery development: "give a man a fish, and you will feed him for a day, teach him how to fish and you'll feed him for life". Such simple wisdoms can too easily have their drawbacks. For fisheries, while the success of modern technology may have fed many for life, it may now threaten the livelihoods of future generations who might have been supported by these resources. The proverb has then been modified by those who have seen the technology of aquaculture as a new "blue revolution": teaching the man how to grow fish was thus proposed as a means to compensate for the shortfall arising from over-exploited capture fisheries, signifying a change from the hunter gatherer to farmer.

Aquaculture "denotes all forms of culture of aquatic animals and plants in fresh, brackish and marine environments" (Pillay, 1990). The historical evidence of aquaculture is reported to go as far back as 2500BC in ancient Egypt and 500BC in China (Pillay, 1990), although it is over the last two or three decades that this has become a rapidly expanding, globally recognised food production sector.

During the 1970s the promise of aquaculture attracted policy makers and investors in both developed and less developed countries (LDCs). Investors were attracted by the potential for high returns, and many were motivated by an interest in fish, or the status accorded by having a fish farm. Researchers and development planners saw a wider range of potential benefits of promoting these new technologies. There was a widely perceived view that aquaculture could provide cheap fish for the poor of the developing world. In 1971 the United Nations reported that "Protein malnutrition, which is a problem of crisis proportions for the developing countries, must be recognised by the entire world community as a threat to world peace and stability which it can ignore only at its own peril" (Edwardson et al., 1981). Some of the first attempts to introduce aquaculture to rural Africa were motivated by the nutritional goals: in Malawi, early attempts by the British Colonial Office to introduce aquaculture are reported to have been promoted by the findings of a report on nutrition produced by the League of Nations in 1935 (Kalinga, 1991). Aquaculture was also seen as a means to stimulate rural economic development through the exploitation of under or un-utilised resources. The UN World food Conference, 1974, identified the fact that much of the potential area for expansion of aquaculture consists of mangrove swamps, estuaries, lagoons, lakes, and shallow coastal waters, where there was very little competition with other rural activities (Gerhardsen, 1976).

These broad goals of aquaculture development were summed up in the Kyoto Declaration on Aquaculture, following an FAO technical conference in Kyoto, Japan, in 1976 (Pillay and Dill, 1979). The identified attributes of aquaculture included production of food of high nutritional value; revitalizing of rural economies by providing income and employment; the potential to utilise low grade foods and wastes to provide high grade protein; the potential for integration with other rural farming activities and the potential to contribute to the enhancement of natural fisheries. The declaration concluded that

> "aquaculture merits the fullest possible support and attention by national authorities for integration into comprehensive renewable resource, energy, land and water use policies and programmes, and for ensuring that the natural resources on which it is based are enhanced and not impaired".

The aquaculture industry has undoubtedly seen great success over the last two decades, with world production increasing from less than 3 million tonnes in the early 1970s to over 19 million tonnes by 1992, dominated by inland fish production in Asia (Table 1.1). Excluding aquatic plants, aquaculture in 1989, at about 11 million tonnes, represented about 11% of the total world fishery products, 16% of the total consumed (only 70% of fishery catch used for human food), and 4% of total animal protein production (New, 1991). Although still a small proportion of the total, this is clearly an important global sector in its own right. In terms of official development assistance, the total aid in the period from 1985 to 1989 was about US$ 834 million. Of this 80% was to Asia, 11% to Africa, 4% Latin America (New, 1991).

Table 1.1 World aquaculture production statistics and forecasts (millions of tonnes)

Year	1970	1975	1983	1985	1987	1989	1991	**1992**	**1992**	*2000*	*2050*
Data Source	a,b	..	a,b	c	c	c	d	e	% share	*f*	*f*
TOTAL	2.6	6.04	10.50	11.00	12.86	14.04	16.55	**19.29**	**100%**	*26.90*	*51.80*
BY TYPE											
Fin Fish	2.6	3.98	4.67	5.06	6.55	7.32	8.74	**9.42**	**49%**	*14.4*	*29*
Molluscs	?	0.99	3.30	2.23	2.70	3.12	3.10	**3.5**	**18%**	*4.9*	*8.9*
Algae	?	1.05	2.39	3.43	3.02	2.99	3.90	**5.39**	**28%**	*5.8*	*9.8*
Crustacea	?	0.02	0.13	0.28	0.59	0.61	0.81	**0.98**	**5%**	*1.8*	*4.1*
BY ENVIRONMENT (Excluding Algae)											
Inland (fresh)				4.14	5.46	6.06	8.31	**9.05**	**65%**		
coastal (brackish and marine)				0.92	1.04	1.26	4.37	**4.87**	**35%**		
BY CONTINENT											
Asia				8.93		11.71	13.24	**16.20**	**84.0%**		
Europe and near east				1.14		1.57	2.15	**1.91**	**9.9%**		
N. America				0.39		0.53	0.66	**0.71**	**3.7%**		
S. America				0.07		0.15	0.33	**0.35**	**1.8%**		
Africa				0.06		0.10	0.17	**0.10**	**0.5%**		

Sources- a: Pillay (1976). b: Pillay (1990). c: New (1991). d: FAO (1993). e: FAO (1994). f: Csavas, (1994).

1.2 Aquaculture methodologies

Aquaculture is a biologically based economic activity, and constitutes a range of water based production systems which harness natural resources and energy, by technological intervention, to achieved desired production objectives, primarily, but not exclusively, food production for economic gain. As with any other biological production system, it seeks to harness and control the characteristics of the "natural environment", creating change, which in addition to the desired objective, has other feedbacks and impacts on that environment. Classification of aquaculture technologies can be made in terms of a range of criteria illustrated in Table 1.2 (see Bardach et al, 1972; Pillay, 1976; Shang, 1981; Huet, 1972). The criteria for level of intensity are broadly similar to those for other livestock and crop production processes. These reflect the resource use patterns of the system in a continuum from relatively minor manipulations of natural production systems, to those which are almost completely controlled by technological intervention.

Table 1.2 Classification of aquaculture technologies

Criteria	Examples
- type of organism(s)	fish, shellfish, crustacea, plants.
- purpose of the culture	commercial gain, or home use, food products, or other goods, restocking for food or recreational fisheries.
- location	marine, brackish, fresh water environments.
- type of facilities	ponds, manufactured tanks or channels, floating net cages, ropes, other specific structures.
- the level of intensity	extensive, semi-intensive, intensive.

Increasing intensity increases the degree of confinement of stock and level of output from a given size of facility (decreasing land or sea area), and consequently increases the input of resources derived from outside the facility boundaries, and the export of wastes. For fin fish and crustacea culture, this is reflected in the increasing degree of replacement of natural feeds with industrially manufactured feeds (Huet, 1972), in effect changing from net exporters to net importers of nutrients. In the case of shellfish and algae, most (but not all) culture systems rely on natural productivity, and so remove nutrients from the system.

1.3 Statement of the problem

In production terms, the forecasts for growth made in the 1970s have been generally achieved. The targets arising from Kyoto in 1976 (Pillay and Dill, 1979) aimed at doubling production to 12 million tonnes by 1985, a figure actually achieved in 1986. More recent forecasts suggest an output of about 25 million tonnes by the year 2000 (New, 1991; Csavas, 1994). New (1991) has examined the problem of maintaining current per-capita fish production in the face of population growth forecasts. Assuming that the fisheries output will level out at about 100 million tonnes[1], he predicts a shortfall

[1] Output in 1990 was 88 million tonnes. More recent forecasts (Csavas, 1994) suggest that total production may have already reached its peak at about this level.

of about 20 million tonnes by the year 2000, and 65 million tonnes by 2025, and that both the need, and the potential for aquaculture growth, is primarily in the developing world.

However, as with the "green revolution", the "blue revolution" may not live up to expectations. Firstly, rather than helping the poor, much of the recent growth in output has been of luxury species, such as marine shrimp, and beneficiaries have been the rich and powerful (New, 1991). The poor may actually end up losing. Weeks (1990) observed that "commercial aquaculture can negatively affect the rural poor, through resource competition, altered familial work patterns, increased unemployment, and degradation of nutrition". Even where producers are part of rural communities, producing relatively low value species, it is rarely the poorest members of the community who produce or consume aquaculture products (Stewart, 1993a; Harrison et al., 1994).

Secondly, the Kyoto concepts of developing under-utilised resources, enhancing rather than impairing natural resources, appear to have been largely neglected for more immediate financial considerations. More seriously, perhaps, what had been seen as under-utilised resources in some cases have actually been the base for important local or regional economic activities, and aquaculture has had a considerable unrecognised opportunity cost. This is particularly evident in the case of shrimp culture developments, which have had a history of rapid development, high profits, and collapse due to over-exploitation of the local resource base, leaving an unusable depleted environment, which may have previously supported a range of commercial and subsistence level activities (Ruitenbeek, 1991).

Finally in the context of the development assistance directed toward aquaculture, there have been many unsuccessful attempts to introduce new aquaculture technologies, particularly in the African continent (UNDP/NMDC/FAO, 1987), where a retrospective view could suggest that in crude financial terms, it may have been just as useful to "give a fish" for the days meal.

It is clear that simply "teaching a man to grow fish" is not enough in attempting to contribute to the ever increasing problems of poverty and needs for food production into the next century. There are questions of who is being fed, and who is in need; who benefits, and who loses in the process of development and change; there are issues of efficiency of resource use, and the conflicts between the short term gains at the expense of long term needs. These aspects have, at best, been a side issue in the observed aquaculture revolution.

1.4 The research objectives and structure

The growing recognition of these problems has come at a time when all aspects of human activity and needs are being increasingly examined in the context of the limited capacity of the global system to support existing and future populations. The themes of sustainability and environment have become an essential component of development planning, corporate and product image creation and political rhetoric. This is equally true for aquaculture development programmes.

What does this mean, and what implications does the concept of sustainability have for the activities of individuals, the development advisors, policy makers and others involved in future aquaculture developments? How are we to pursue sustainability?

The aim of the thesis is to investigate whether, and if so how, sustainability of aquaculture developments can be defined and assessed: a specific objective is to identify means of assessment which are workable across the entire spectrum of aquaculture activities. As a systems based problem, this presents significant difficulties in presentation of the final document: the linear form of the written word contrasting with the non linearity of real world problems, which feature interconnections and feedbacks at a wide range of levels in time and space. A further problem arises due to the breadth of issues which are relevant to this study, and the need to achieve some depth to the analysis. It is not possible, nor necessarily desirable, to attempt to investigate each type of aquaculture technology, or every available assessment methodology. The objective is therefore to highlight key issues and examine a range of assessment methods, from which an approach to the assessment process can be developed. An attempt is made to balance the problems of breath and depth by structuring the document in four main sections: the relationship between these is illustrated in Figure 1.1. The content of each sections is as follows:

Section 1

Having outlined the broad context of aquaculture as a growing natural resources sector, the following three chapters here present; first, an overview of the main issues and concepts of sustainability; second, an outline of the needs of the assessment process (in terms of key themes, indicators and systems perspectives); third, a review of the range of impacts and system interactions associated with aquaculture developments, and proposals for a range of broad indicator categories which may be relevant to the assessment process.

Section 2

Aspects of sustainability and approaches to assessment are examined in the context of three case studies, each focusing on a different theme. These include: monitoring and assessment of environmental interactions of an intensive fish farming operation in Scotland; an analysis of resource use assessment methods, focusing on the use of energy as an evaluative indicator; an analysis of a development process aimed at creating sustainable aquaculture in rural communities in Malawi. Each case is intentionally narrow, providing the opportunity to explore specific aspects in detail.

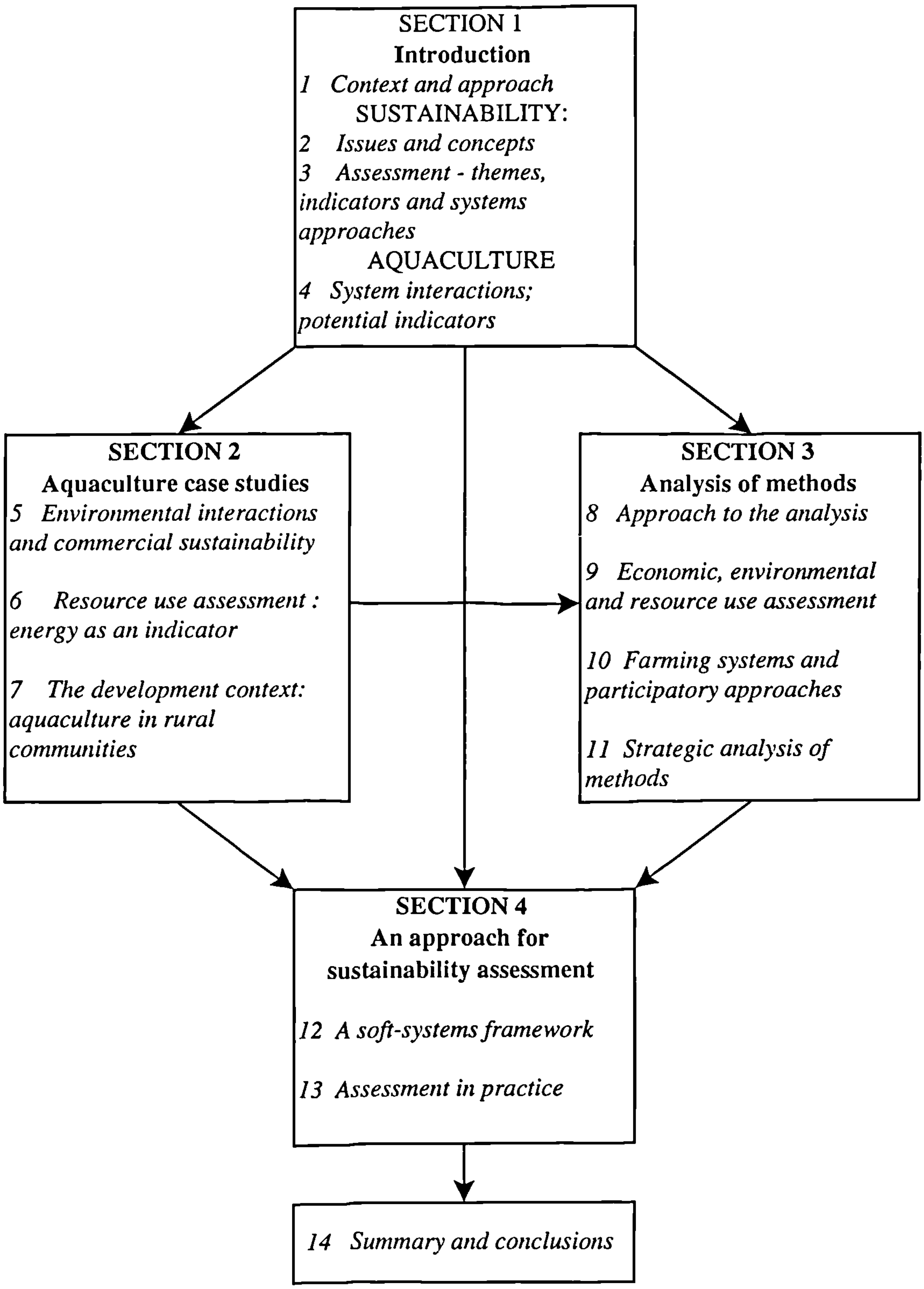
Section 3

A more broad ranging analysis of a selection of largely generic appraisal approaches is presented. This is set in the context of a range of criteria for the assessment process, developed here, and evaluated in terms of potential applicability at a range of system levels.

Section 4

Finally, based on the analyses in the previous chapters, a standardised approach is proposed by which issues of sustainability may be incorporated into the assessment process across the spectrum of aquaculture developments. The application of this to a selection of aquaculture systems is demonstrated.

Figure 1.1 Structure of the thesis



Numbers: Chapter subjects

Chapter 2

Sustainability: issues and concepts

Chapter 2 Sustainability: issues and concepts

2.1 Background

In the last decade "sustainability" has become a key word in the objectives of most governments and development organisations. The dictionary definition of sustain is to "keep, hold up, endure, keep alive". The concept of sustainability in the context of human activities has its roots the growth of the environmental movement of the 1960s and '70s in the west, and, in less developed countries (LDCs), the perceived shortfalls in the capacity of technology transfer and economic growth to overcome increasing problems of poverty. The objective of this chapter is to outline the background to the development of current ideas on sustainable development, highlight the key concepts, and introduce the main themes to be investigated in this study.

There is no clear starting point in the debate concerning humans and their environment. Malthus, in the 18th century, is commonly regarded as one of the earliest writers to recognise the limitations of our world, in the context of likely exponential population growth, and at best arithmetic growth in food supply (Kula, 1994). Through the 19th and early 20th century authors such as Mills, Rechart and Jevons (reviewed by Kula, 1994) raised questions about growth, consumption, limitations of resource supply and quality of life.

In the late 1940s and 1950s, most industrialised societies went through a period of very rapid economic growth bringing increases in material standards of living for large proportions of the population. The problems of increasing population and poverty in LDCs were the focus of growing international development assistance, primarily based on the transfer of technology to stimulate increased agricultural production and industrialisation. The resulting economic growth, which had so benefited people in the west, would, it was assumed, "trickle down" to improve the lot of the poor.

It was in the 1960s that the first real challenge arose to the concept of economic growth as a solution to mans needs. The "cost" of growth was beginning to be questioned by the environmental movement, which highlighted local and regional conflicts between the needs for economic development, and the need to preserve the natural environment.

The growing concern with environmental damage was a central theme of the UN Conference on the Human Environment in 1972, which led to the development of Environmental Protection Agencies in a number of countries. Nevertheless, the dominant view held environmental problems to be a separate issue, or at best economic externalities in the process of development. This is exemplified in the approach of Little and Mirrlees (1974) in discussing the issue of externalities in the cost benefit approach to project appraisal. They considered that "envisaging such (ecological) effects, which may be better called unintended than external, is outside the realm of economics", although they did acknowledge that "once their probability is established, the economist may be called upon to appraise them".

In LDCs, faith in technology transfer and economic development was also being challenged. Thus Adelman and Morris (1967) found that in the poorest countries in Africa and Latin America (with a per capita income of < US$500 per year), "development tends to bring both relative and absolute impoverishment to the poorest 60% of the population", and concluded that policies needed to benefit the poor were not the same as those to maximise growth.

Two themes were therefore arising: the environment, and the problems of meeting basic human needs. The first major work to set concerns of meeting the needs of human populations in a future and global context was "Limits to Growth" (Meadows et al, 1972). The models presented, based on predictions of future trends in population growth and resource exploitation, painted a rather bleak picture. Although their basic assumptions have since been questioned (Pearce et al, 1989), they still highlight the major concern today. The next decade saw a growing recognition of conservation of the natural environment as an essential component of development. The World Conservation Strategy (IUCN, 1980) identified this in the concept of sustainable development. This recognised "our responsibilities as trustees of natural resources for the generations to come", and the fact that "development and conservation are equally necessary for our survival". It was not clear, however, how this objective was to be linked with economic policy objectives or potentials (Pearce et al, 1989). In 1986, the IUCN Ottawa Conference on Conservation and Development emphasised the need for life and earth to be viewed as an integrated system, if sustainable development was to be achieved (Jacobs and Munro, 1987). This identified the need for integration of conservation and development, the importance of meeting basic human needs, of equity and social justice, of cultural diversity and ecological integrity (Jacobs et al, 1987).

These concepts were further developed, with a clearer emphasis on futurity, in the "Bruntland Report" of the World Commission on Environment and Development (WCED 1987). This represented the first major recognition of the broader goal of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Although this report generated criticisms (eg Redcliff, 1987; Engel 1990; Goodland, 1991), it represented a landmark in the debate and stimulated a range of follow up activities leading to the "Earth Summit", UNCED, in Rio, 1992. There was also a dramatic increase in media attention given to issues of global environmental change, highlighted by concerns of global warming and ozone depletion: the perception of rushing headlong into disaster caught the attention of public and politicians. While the Rio summit was again criticised for the limitations in practical outcomes, it was particularly significant for the high political profile it generated internationally, "north" and "south", for the concept of sustainable development, and the need for integration of environment and development policy. A significant output was "Agenda 21" (UNCED, 1992), which according to Levett (1993), set out "the most thorough and ambitious attempt yet to specify what actions will be needed to reconcile development with environmental concerns."

There has also been a growing volume of academic literature dealing with the concept and problems of a more sustainable approach to the process of economic development. While the broad concept of the Bruntland Commission definition is generally accepted, there is a wide range of interpretations and viewpoints in specifying exact meaning and implications for future economic policy and development. There is, however, a broad consensus on the main themes, as follows (see reviews by Pearce et al., 1989; Robinson, 1990; Lele, 1991; Chambers and Conway, 1992):

- the need to meet basic human needs in the form of material, social and cultural wellbeing (termed "sustainable livelihoods" by Chambers and Conway, 1992).

- the need to address questions of inter and intra generational equity, in which capability of individuals and communities is central.

- the need to recognise the role of the natural environment in providing both goods and services as a foundation for human society, rather than an externality.

- the need to maintain or enhance this capacity for future generations.

An underlying concept of sustainability is that we can no longer consider the activities of the human system to be somehow separate from the "ecosystem", the biotic and abiotic processes sustaining life, including our own. While this may be self evident to many, and is incorporated in the belief system of many cultures, it has not been reflected in the activities of the dominant industrialised societies of the present day, founded on a perspective of separateness and dominion. It can be argued that it is not the precise definition of sustainability that is critical, but the new world view which it represents, in which case it can perhaps be better described as a direction, rather than a goal or "solution", with many potential paths.

2.2 Practical concepts

2.2.1 Changing economic approaches

As outlined above, critics of the traditional approach to economic development contend that decision making criteria in dominant societies, whether centrally planned or free market, ignore the life supporting role and finite capacity of the natural environment. As Kula (1994) notes,

> "conventional economic thinking envisages a through-put system in which economic activity moves from extraction of natural resources to the rubbish dump and the ultimate physical product turns out to be the waste. Sooner, rather than later, this process is going to come to an end".

Conventional economic models are also criticised for their inability to deal with issues of welfare and equity. Criticisms of the concept of growth are of course not recent. Nordhaus and Tobin (1972) described the problem with the neo-classical economics as follows:

"the prevailing standard model of growth assumes that there are no limits on the feasibility of expanding the supplies of non-human agents of production. It is basically a two factor model in which production depends on labour and reproducible capital. Land and resources, the third member of the classical triad, have generally been dropped... "

Rees and Wackernagle (1992) point out the apparent contradiction in definition and practice of economic theory: defining economics as "the scientific study of efficient allocation of scarce resources (energy and material) among competing uses in human society", in practice the dominant paradigm "lacks any representation of materials, energy sources, physical structures and time dependent processes basic to an ecological approach" (latter quoting Christensen, 1991).

The practical application of economic theory for assessment of development projects is the process of cost-benefit analysis (CBA), based on neoclassical welfare economics (Pearce and Nash, 1981; Johansson, 1991). This originated in USA in the late 1930s as a tool for the assessment of public sector projects, comparing the gains and losses to society beyond the direct financial measures applied in commercial sector decision making, aggregated in a set of money valuations. On the basis of the growth criterion, a tool central to CBA, and therefore to economic decision making, is the process of discounting the future costs or benefits associated with a particular activity: this accounts for both opportunity value, and the social time preference for something now rather than later, reflected in the 'time value of money'. The main criticism of discounting in satisfying sustainability is that high discount rates, typical of current market rates, substantially devalue future impacts of current decisions. Costanza and Daly (1992) liken discounting to a "semi rational, sub-optimising behaviour known as a social trap" which results from short run behaviour which is inconsistent with long-run interests. Lowered, zero or even negative discounting rates are therefore proposed to satisfy the futurity of sustainable development.

In contrast, Pearce et al. (1989) argue that while future catastrophic costs may not always be given their true importance, there is "no unique relationship between high discount rates and environmental deterioration". Lowering discount rates will not necessarily help the environment, as it may increase profitability of projects with negative environmental effects. Sterner (1992), considering the impossibility of long run growth, proposes that the exponential single discount rate might be replaced by a non linear discount schedule, although the difficulties in the choosing appropriate rates is acknowledged. While acknowledging the limitations of discounting, Pearce et al. (1989) argue that these should be overcome by other means, including the improvement of valuation techniques for future costs and benefits, the integration of environmental considerations into all economic decisions and incorporation of a sustainability constraint into the appraisal process.

The conventional economic model is also criticised for failing to deal adequately with the problems of welfare and equity. As an indicator of successful development, economic growth (in terms of increasing GDP and GNP), deals only with flows of money, with no measure of the value to society at large, let alone the welfare of individuals (Daly and Cobb, 1989; Pearce et al., 1989; Chambers and Conway, 1992). The apparent failure of the "trickle down effect" has been mentioned above.

This raises an important question of the extent to which there is a conflict between the concepts of economic growth and sustainable development. "Development" in the context of indicators such as GNP, has tended to carry growth related goals. However, for sustainability, a clear distinction can be drawn between growth and development, the latter implying broad change for the better throughout society, through increasing efficiency, without necessarily increasing in scale or throughput (Costanza and Daly, 1992).

The problem is therefore how to incorporate sustainability into practical action, into 'rational' economic decision making. It has been argued that Cost Benefit Analysis (CBA) already provides the framework for including environmental and social concerns, and what is at issue is the "extent to which the valuation procedures are employed, and what the added potential is for their use" (Pearce et al., 1989). Economists therefore argue that the neoclassical model is still good, but its boundaries need to be widened. This includes the established field of welfare economics focused on the social aspects of development (see Johansson, 1991), and the more recent analysis of environmental issues, which can be considered to form the field of environmental economics (eg Tietenberg, 1988).

The problem areas in applying CBA to the environment, and the main areas of research in environmental economics, have been summarised by Hanley and Spash (1993) as follows:

- The valuation of non-market goods, such as wildlife and landscape. How should this be done, and how much reliance should society place on estimates so generated? Are we acting immorally by placing money values on such things?
- Ecosystem complexity: how can society accurately predict the effects of human activities on ecosystem structure and function?
- Discounting and the discount rate: should society discount? If so, what rate should be used? Does discounting violate the rights of future generations?
- Institutional capture: is CBA a truly objective way of making decisions, or can institutions capture it for their own ends?
- Uncertainty and irreversibility. How will these aspects be included in a CBA?

Critics of CBA raise a number of fundamental objections. Bowers (1990), addressing the first two issues (in response to Pearce et al., 1989), considered that:

> "there are no techniques which give acceptable valuations of the natural environment. All techniques... are open to serious objections. The intractable issues of uncertainty over the value of natural ecosystems and the stock of genetic capital are probably best dealt with by strict rules of conservation. Monetary valuation has little role to play in this process and indeed can serve to deflect attention from the fundamental issues".

Continuing on this argument, Lave and Gruenspecht (1991, in Rees and Wackernagle, 1992) argue that "difficulties with missing data, uncertainty, and too little time and resources for an exhaustive analysis combine with theoretical difficulties to make ineffectual any serious claim that an applied study produces an optimal or theoretically justified outcome". In practice, there remains the tendency to ignore aspects which cannot be given a monetary value. Rees and Wackernagle (1992) also question the conceptual basis of the approach. They argue that this view of the world is too limited, that:

"ecological analysis reveals that humankind remains in a state of obligate dependency on numerous biophysical goods and services with great positive economic value but for which the are no markets or feasible substitutes. In the absence of markets, the already questionable scarcity indicators of conventional economics- prices, costs, and profits - fail absolutely...".

Concerning institutional capture, it can be argued that in the process of condensing all values into one numeraire, and selection of discount rate, the sensitivity to changes in value assumptions hidden behind the figures means that CBA is very easily manipulated to produce an answer that is sought rather than 'true'.

These criticisms do not necessarily suggest that CBA has no place in evaluation: it remains an important technique for dealing with market related values. However, in valuing less tangible aspects of environment and utility, its usefulness must be set "clearly within the context in which the CBA results operate", acknowledging the fact that this approach "is but one piece of relevant information in taking a decision" (Hanley and Spash, 1993).

While there is therefore considerable debate on the extent to which CBA can address issues of sustainability, there is widespread perception of the inadequacy of current economic models. This is based primarily on the narrowness of valuation criteria applied, and the lack of effective mechanisms to value "externalities". The need to extend boundaries of decision criteria has increasingly called for a wider, systems based perspective to provide an appropriate rationale.

2.2.2 Sustainability as a systems concept

Systems have been defined as "groups of interacting, interdependent parts linked by exchanges of energy, matter and information" (Costanza et al., 1993). Systems boundaries provide a means of breaking down complex systems into components, subsystems, to understand better the structural and functional relationships within defined limits, and between systems. Unlike the reductionist approach of "traditional" science, systems science is focused on function and links, rather than individual organisms and processes. The sustainability of human managed production process, or systems, can therefore be seen to relate to the requirements for external inputs and the production of outputs, and how these interact with associated and enveloping systems.

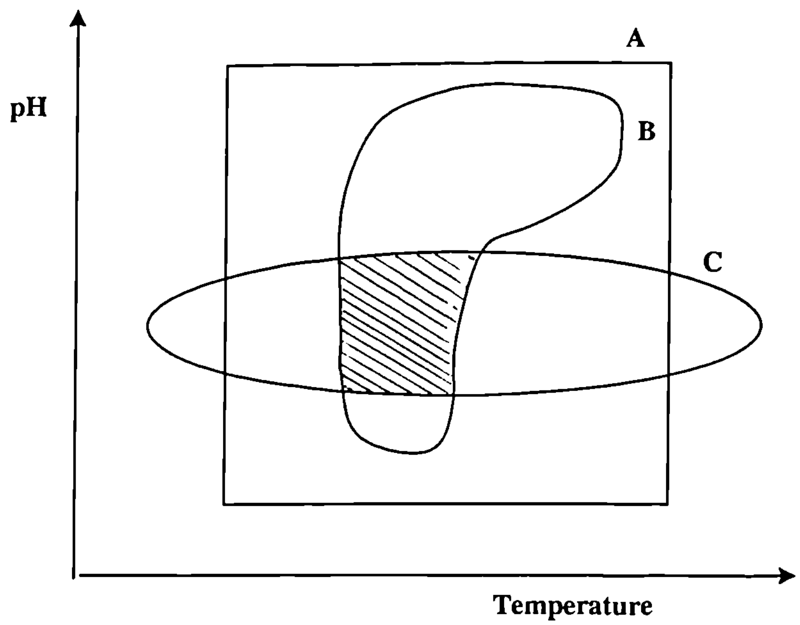
In a systems view, the widest boundaries for practical purposes are set by the globe, essentially a closed system, the sustainability of which relies on the continued energy flux from the sun driving the internal processes and transformations comprising life on earth. This complex, adaptive, evolutionary system contains essentially open, interacting complex subsystems representing natural and human systems. The state of the system at any time can be "represented as a point in a high dimensional phase space whose axes are the control variables and whose coordinates are their current values" (Clayton and Radcliffe, 1992).

It is clear that the sustainability of this global living system does not necessarily require sustainability in terms of existence of species. Extinction has been part of the evolutionary process on earth since life began, bringing changes in both species and functions, and the environment itself. The condition of sustainability does require that activities or processes carried out by species do not jeopardize the ability of living systems to function. Sustainability from the human perspective therefore significantly narrows the boundaries of acceptable futures for sustainability to those not only suitable for global life processes (see Lovelock, 1987), but also for human survival (see Figure 2.1). At this level, global models demonstrate a wide range of possible futures if current trends in human activity continue, depending primarily on the assumptions concerning the ability of technological development to overcome problems as they arise. In considering domains in which human life is 'possible', sustainability also embodies notions of acceptable quality of life for present and future generations, in which equity is an important feature.

Human commitment to sustaining other life forms, 'moral stewardship', must therefore also be seen as anthropocentric: this is not simply an issue of ecosystem parks for the sake of other life, but dependence on the global ecosystem. This context of dependence provides the argument for a more ecological approach to economics, based on an understanding of both ecological and human systems, and of how they function and interact.

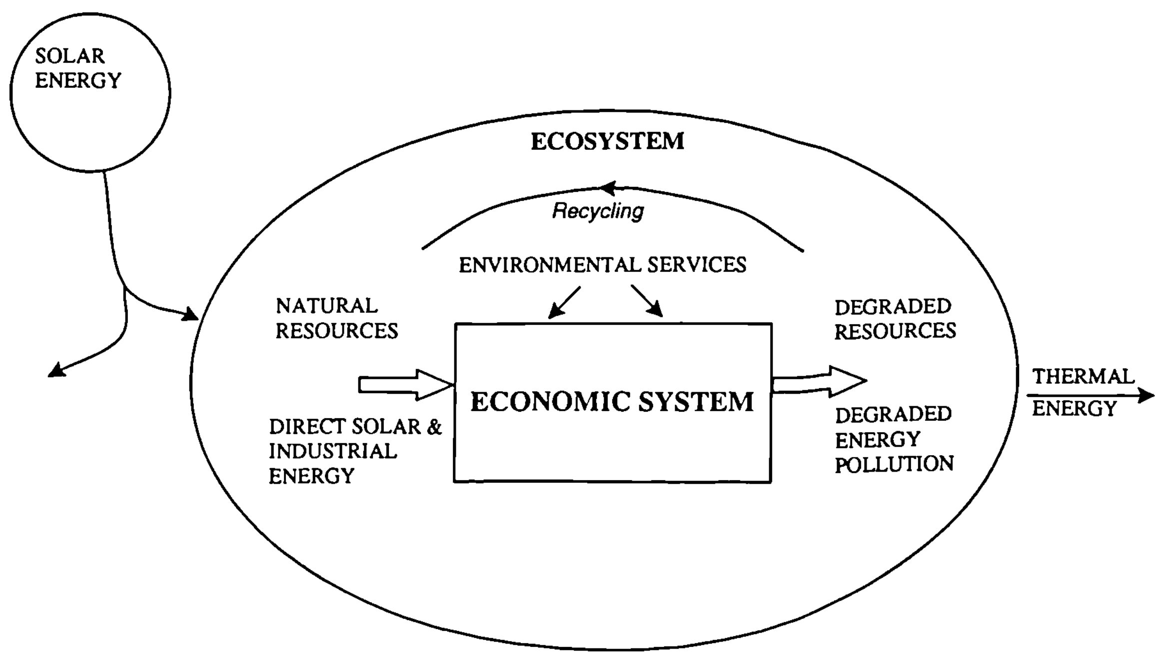
Figure 2.1 Two dimensional section through phase space for earth

Suggests possible survival regions for three systems, A, B and C. System A can tolerate a wide range of pH and Temperature, but depends on regions B and C, which can not. The effective survival region for A is therefor the intersection between the three survival regions



(Source: Clayton and Radcliffe, 1992)

Figure 2.2 The economic system as an open subsystem of the ecosystem



(Source: Folke, 1990)

2.2.3 Societal - Ecosystem relationships: widening the economic model

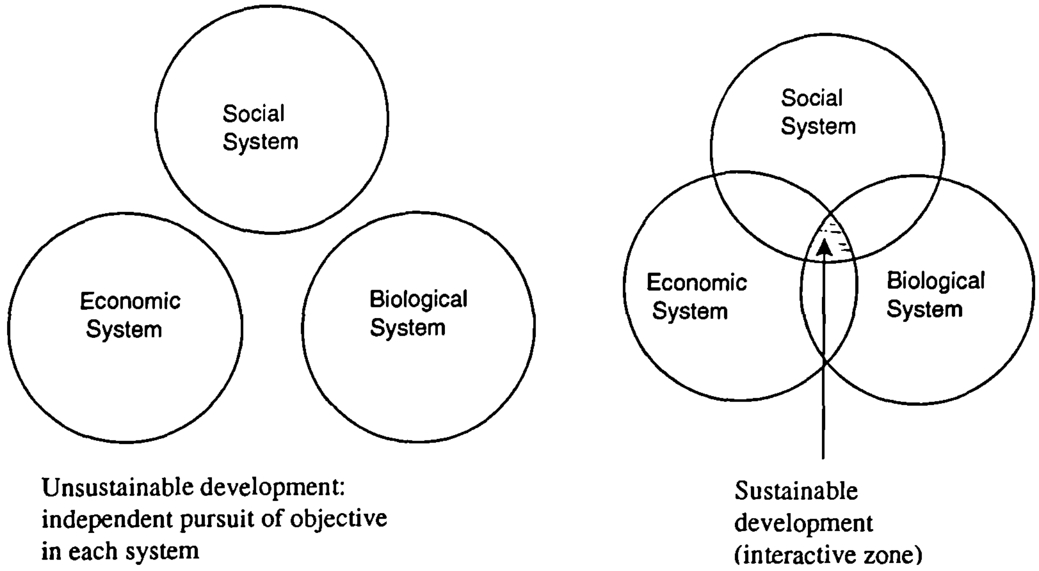
In simple terms, approaches to widen the boundaries of analysis can be considered under two broad areas: environmental economics, outlined earlier, and ecological economics. The latter arises from an ecological perspective, and is proposed as a more holistic, systems based approach to understanding the relationship between human society and the environment (Costanza, 1989). In this the "traditional" view of economics is but a subsystem (Figure 2.2). Ecological economics aims to incorporate a systems ecology approach with an emphasis on "connectivity, particularly material and energy flows in relation to the functional integrity of ecosystems"(Rees and Wackernagle, 1992).

In this broad context, Barbier (1987) proposed that sustainability objectives can be considered in terms of three basic systems: the biological, or natural environment system; the economic system and the social system (Figure 2.3). He recognised that sub-objectives of goals in these separate systems may be in conflict, and suggested that the objective of sustainable development would be to maximise goal achievement across these three systems. This would inevitably involve choices and trade-offs.

In a related conceptual model, Berkes and Folke (1992) illustrated the relationship between humans and their environment, in terms of three basic elements: natural capital (NC), cultural capital (CC) and human made capital (HMC) (Figure 2.4). HMC refers to the manufactured element of the neoclassical model's capital, the produced means of production. The term cultural capital has been used to describe the attributes of human societies which influence the way they interact with the natural world, tied up in systems of beliefs, world view, knowledge and institutions. These have varied greatly through the ages, and between different societies, but are currently dominated (in terms of the approach to economic activities) by the values of the industrialised world, in which dominant world view is one of separation from and dominion over nature (Kula, 1994). This definition may also be extended to include intangible social and cultural aspects which contribute to 'quality' of life, unrelated to material aspects of wellbeing.

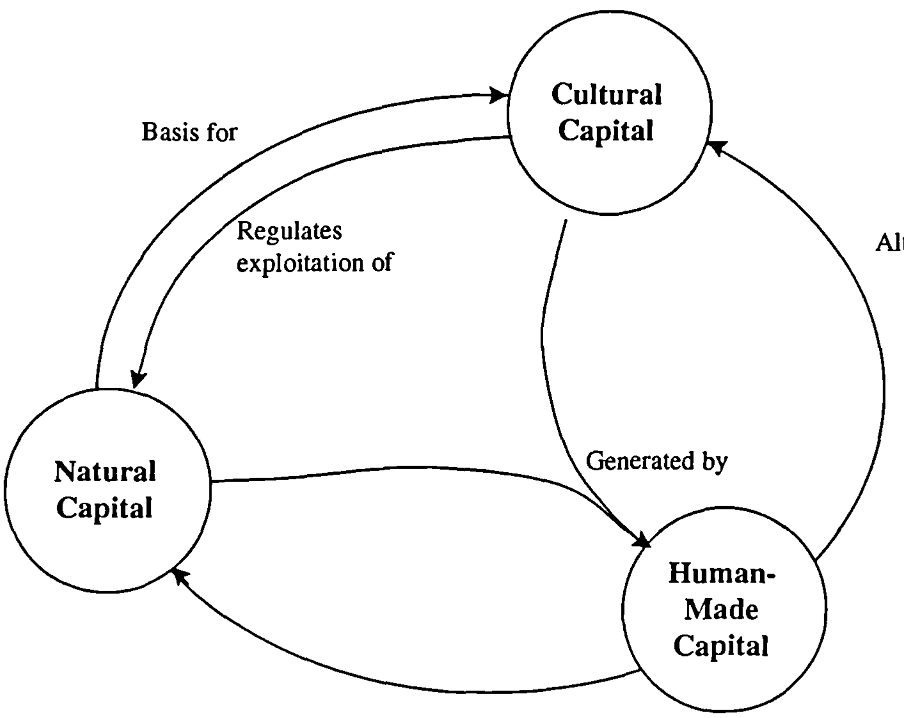
Natural capital refers, in a narrower sense, to the natural resource base providing goods and services to human society at present, and in a wider sense, represents the diversity and the future potential of the global ecosystem.

Figure 2.3 Sustainable development as a process of trade-offs between subsystem objectives



(from Barbier, 1987)

Figure 2.4 First-order interrelationships among natural capital (NC), human-made capital (H-MC) and cultural capital (CC).



(from Berkes and Folke, 1992)

Costanza and Daly (1992) differentiate between renewable (RNC) and non renewable (NNC) natural capital. The former "is active and self-maintaining using solar energy". Ecosystems represent RNC which can yield goods (such as fish and timber) and provide services (coastal protection, water purification, recreation, aesthetic values). As dynamic and evolving interactions between the biotic and abiotic elements of the natural world, ecosystems also represent sources of potential, as yet unknown, goods and services to humanity. The basis of RNC, and therefore these derived human benefits, is the diversity of life on earth, or biodiversity, recognised by the Earth Summit in Rio (UNCED, 1992) as a fundamental aspect of sustainability (Ambio, 1992 & 1993; Barbier et al, 1994; Perrings et al., 1994). Non renewable capital (NNC), principally represented by fossil fuels and mineral deposits, are passive and finite stocks which generally yield no service until extracted. El Serafy (1989), quoted by Costanza and Daly (1992), suggests that "RNC is analogous to machines and is subject to entropic depreciation: NNC is analogous to inventories and is subject to liquidation".

The relationships between these three elements of the model have been highlighted by Berkes and Folke (1994), who proposed that:

> "natural capital is the basis for cultural capital, which is evolved and evolving from our interactions with both the natural world (NC), and the created world of human made capital (HMC). Human-made capital is generated by an interaction between natural and cultural capital. Cultural capital will determine how a society uses natural capital to create HMC.......aspects of cultural capital, such as institutions involved in the governance of resource use and the environmental world view, are crucial for the potential of a society to develop sustainable relations with its natural world".

Central to this is the issue of property rights, and participation in the process of resource management: Ostrom (1993) points out that, at a local level, for ecosystem management regimes to be effective, there is a need for the users of ecosystem goods and services to be closely involved with the development and modification of management procedures and rules, and the enforcement of those rules. The role of participation is discussed further below.

2.4 Perspectives for future decisions

2.4.1 A range of possible futures

There are strongly conflicting views on the implications of current trends. Pessimistic models of the future predict an imminent collapse of the economic system (within a century) due to over-exploitation of the natural resource base, bringing world wide human disaster (Meadows et al, 1972). They therefore call for drastic reduction of this exploitation, and urgent action to control and remediate environmental damage. Optimistic models, on the other hand, consider that resource depletion should not be seen as a fundamental problem, as scarcity and price mechanisms will lead to conservation and the search for substitutes (Barnett and Morse, 1963; Dasgupta and Heal, 1979), suggesting that "the world can, in effect, get along without natural resources" (Solow, 1974, in Rees and Wackernagel, 1992). Based on past evidence, which illustrates that technological advances can allow substitution for the depletion of the natural resource base (Victor, 1991), some see a future where humans are "numerous, rich and in control of the forces of nature"(see Tietenberg, 1988, Chapter 1).

These extremes illustrate the problem in seeking sustainable development: there is no clear "right" way. The implications of adoption of either of these approaches for future policy, and the event of these being "right" or "wrong", has been presented by Costanza (1989) in a "pay-off matrix" (Table 2.1).

Table 2.1 Payoff matrix for technological optimism vs. scepticism

REAL STATE OF THE WORLD

	If the optimists are right	If the sceptics are right
Optimists policy	High	**Disaster**
Sceptics policy	Moderate	**Sustainability**

(Source: Costanza, 1989)

This suggests that in the face of environmental uncertainty, the optimistic and pessimistic models, as a basis for policy, represent respectively, high and low risk options. In practice, while most of the sustainability debate falls between these categories, current action of human society appears to be taking the high risk option. Although this simple model might suggest that seeking change to more sustainable society should involve a more precautionary approach, that the stakes of being wrong in the high risk options are too great, in reality this would require trade-offs in which the existing problems of undersupplying the basic needs of current generations may be made even more serious.

2.4.2 Weak and strong sustainability

Pearce (1993) has presented this range of perspectives and potential approaches in the form of a "sustainability spectrum", summarising technocentric and ecocentric views, applying "weak" and "strong" sustainability labels (Table 2.2). One of the key issues between these levels of sustainability is the extent of substitutability between different forms of capital: ie can natural capital be depleted to increase HMC and CC and still provide sustainability? The view classified as weak sustainability contends that it is the aggregate quantity of capital bequest to the next generation that matters, rather than the mix (the 'constant capital' rule). However, Costanza and Daly (1992) present arguments to support the view that "HMC and NC are, in general, complements, not substitutes". They criticise the neo-classical assumption of near perfect substitutability for "mathematical convenience, and perhaps a hubris-driven technological dream of being independent of nature". Based on this, they suggest that the "minimum necessary condition for sustainability is the maintenance of the total natural capital stock at or above the current level". They go on to propose a set of operational principles for strong sustainable development, summarised in Table 2.3.

The maintenance of defined levels of capital acknowledges the importance of inter-generational equity: that "each generation should inherit at least a similar natural inheritance" (Pearce et al, 1989). However, Chambers (1992) notes that with projected population growth, simply maintaining this capital is not sufficient. While accepting that certain resources are not renewable and will be used up, he argues that a more proactive approach to enhancing the natural resource stocks will be required if the individual well being and equity aspects of sustainable development are to be achieved.

Table 2.2 The Sustainability Spectrum

	Technocentric		**Ecocentric**	
	Cornucopian	Accommodating	Communalist	Deep ecology
Green Labels	Resource exploitative, growth-orientated position	Resource conservationist and managerial position	Resource preservationist position	Extreme preservationist position
Type of economy	Anti-green economy, unfettered free markets	Green economy, green markets guided by economic incentive instruments (EIs)	Deep green economy, steady state economy regulated by macro-environmental standards and supplemented by EIs	Very deep green economy, heavily regulated to minimise 'resource take'
Management strategies	Primary economic policy objective, maximise economic growth (GNP) Taken as axiomatic that free markets & technical progress will ensure infinite substitution possibilities, overcoming scarcity constraints	Modified economic growth (adjusted green accounting to measure GNP) decoupling important but infinite substitution rejected. Sustainability rules: constant capital rule	Zero economic growth; zero population growth Decoupling plus no increase in scale. Systems perspective- health of whole ecosystem very important; Gaia hypothesis and implications	Reduced scale of economy and population Scale reduction imperative; at the extreme for some there is a literal interpretation of Gaia as a personalised agent to which moral obligations are owed
Ethics	Rights of the contemporary human individual Instrumental value (to humans) in nature	Extension of ethical reasoning, caring for others' motive - intra and inter-generational equity Instrumental value in nature	Further extension of ethical reasoning: interests of the collective take precedence over the individual: Primary value of ecosystems and secondary values of component functions and services	Acceptance of bio-ethics (moral rights on all species, parts of the environment) Intrinsic value in nature
Sustainability labels	Very weak	Weak sustainability	Strong sustainability	Very strong

(Source: Pearce 1993)

Table 2.3 Sustainable development: Operational Principles

1	Limit human scale: - at least within the carrying capacity of the remaining natural capital
2	Technological progress: - efficiency increasing rather than throughput increasing
3	Renewable natural capital (both source and sink functions): -harvesting rates within regeneration rates -waste emission within assimilative capacity of the environment
4	Non renewable natural capital - exploitation rate equal to finding renewable substitutes

(Source: Costanza and Daly, 1992)

2.4.3 Sustainable development as a decision making process

While global sustainability might represent the broader goal, it is at the national and local levels of decision making where most of the action would occur. The problem at this level is that in specific development situations, there will be a need to make trade-offs between conflicting objectives of sustainability in social, economic and environmental systems, and between long term goals and short term needs. Though decision makers might seek to maximise across all three systems, as proposed by Barbier (1987), there are significant constraints in practice. Morgan (1986), drawing on the work of Herbert Simon, considered a number of reasons which limit the ability of human organisations to make rational decisions, arguing that:

> "people (a) usually have to act on the basis of incomplete information about possible courses of action and their consequences, (b) are able to explore a limited number of alternatives relating to any decision, and (c) are unable to attach accurate values to outcomes.... at best they can achieve only limited forms of rationality. In contrast to the assumptions made in economics about the optimising behaviour of individuals, individuals and organisations settle for a 'bounded rationality' of 'good enough' decisions based on simple rules of thumb and limited search and information"

These points may be particularly pertinent to assessing sustainability, in which the goal is unclear, valuation systems are limited, information is lacking, and uncertainty is inherent. It may be necessary to accept that in seeking practical approaches to incorporating sustainability into assessment of specific developments, there is a need for pragmatism in which "good enough" decisions are accepted as a necessary reality, while recognising due limitations. There are two aspects central to incorporating sustainability into decision making. First is the question of who is involved in the process, and the concept of participation. The second concerns the scope of information available, and the problems of dealing with uncertainty

An important aspect of any assessment and decision making process is setting the boundaries for the analysis, which must be broad enough to include relevant linkages within and between systems, but not so broad as to swamp the process with detailed information which may obscure these essential features. Because there are no clearly defined goals, and a wide range of potentially conflicting, but equally valid views of the system, it can be argued that constructive trade-offs can only be realised by an analysis arising from participation of a wide range of stakeholders in the development process (Carley, 1994). Four important features of participation include:

- the raising the level of awareness of those involved in the process.
- providing information on essential dimensions (social, economic and environmental).
- establishing realistic priorities for action from a broad array of options.
- defining what are likely to be sustainable development options and trade-offs.

Another major issue is the need to bring natural resources into the process of assessment, expressed in proposals for developing natural resource accounting at national and corporate levels (Gray, 1994), and in the environmental and ecological economics approaches outlined earlier. A fundamental obstacle to including the natural environment into policy and planning process is the inherent complexity, variability and unpredictability of these systems. In this process, based on legal traditions, environmental policy makers and regulators require information related to concepts such as maximum sustainable yields, known impacts, and risk assessments. However, while they seek unambiguous and defensible decisions, which can be translated into legislative process, the information concerned is often the subject of scientific controversy. In areas of uncertainty this tends to result in policy decisions which are based on the status quo, while waiting for better information.

There is, however, a growing recognition of the practical impossibility of predicting the behaviour of natural systems in which uncertainty is a dominant feature: characteristics of ecosystems such as non linearity, chaotic behaviour, the potential for systems to flip into different stable domains renders the concepts of climax state and maximum sustainable yields as over simplistic and even wrong (Holling et al., 1994)

The problem of the link between science and policy has prompted suggestions for a change in approach to managing the environment. The first concerns the need for more flexible management of renewable natural resources, in which the maintenance of environmental stocks and functions does not necessarily imply a static resource base. The important point is for management to maintain the ecosystem's ability to perform, to provide goods and services, and to change. This implies that management must build in flexibility in the exploitation of renewable environmental resources (Hammer et al., 1993). In ecosystem terms this therefore introduces the concept of maintaining resilience and adaptability of natural capital, rather than stock, in which biodiversity is a key feature (Holling et al., 1994).

The second concerns the way uncertainty is dealt with in the decision making process, which at present commonly relies on the proof of potential negative impacts, which in areas of true uncertainty is not possible. Among others, Costanza and Cornwell (1992) propose a precautionary, polluter pays principle (4Ps) in which the onus of uncertainty is on developers, implemented by mechanisms such as environmental assurance bonds: as a more proactive approach to environmental problems, in which the (currently assessed) cost of potential damage is paid before any damage is done, it is argued that this would create the economic incentives to reduce pollution, research the true costs of environmentally damaging activities and to develop innovative, cost effective pollution control technologies. In judging the potential importance of these aspects, reversibility of environmental change must be considered.

The development of a workable basis for the inclusion of such proposals into decision making and resource management regimes implies a change in approaches to dealing with uncertainty in the interpretation of scientific information at one level, but also a change in the "cultural capital" elements of the systems interactions illustrated above. Given the problems in applying seemingly simplistic resource management regimes (such as maximum sustainable yields from fisheries), due to lack of control over exploitation, implementing decisions which seek more sustainable development clearly represents a significant problem. In this context, the development of institutional structures at all levels in society, both formal and informal, in which resource users participate in management and decision making, is considered to be an important component of the process of seeking sustainability, both in terms of resource management and improved equity (Ostrom, 1993). However, participation carries with it the potential for conflict between popularity and sustainability in resource management policy. This aspect is considered later.

2.5 Problems in application and focus of the thesis

The above discussions cover some of the main sustainability concepts. The question remains as to how best to apply these in the assessment of development. While sustainability has only received widespread attention since the late 1980s, many of the issues of environmental and social concern with the current approaches to economic development have been long studied. In spite of this, there appears to be a very limited application in practice. This has involved the establishment of Environmental Protection Agencies (EPAs) in some countries, and some cases of the use of "contingent valuation" methods to incorporate environmental values in Cost Benefit analysis. Various approaches have been developed, and established in specific sectors and countries, to control pollution, ranging from legislation to tradeable permits, but the applicability of these methods has been generally limited (see Tietenberg 1988). As noted in a recent report by the New Economics Foundation (NEF, 1994a) "to an extent, agreement over the need for sustainable development has been at the expense of clarity over its practical implementation". The problem can be viewed at several levels:

- The first is one of systems boundaries and scale, and the problem of indivisibility. The rational longer term objective of society at large can be seen in terms of global sustainability. To what extent is the sustainability of individual activities a requirement for global sustainability? Can the activities of the individual (firm, or sector, in this case aquaculture developments) be usefully assessed for sustainability without a knowledge of the sustainability of connecting and hierarchical systems?

- The second is the question of indicators of sustainability and methods by which they can be assessed. At a national level the limitations of economic indicators of development have been noted. While there have been some attempts to widen these to incorporate measures of social welfare (eg Measure of Economic Welfare, (MEW) Nordhaus and Tobin, 1972; Index of EW, Daly and Cobb, 1989), there is generally a lack of agreed indicators to measure changes which incorporate environmental and social values. These broad indicators do not address the need for indicators of sustainability which can be applied at a range of levels, from the individual firm, to national and global levels (NEF, 1994 a &b).

- The third is the issue of implementation: how can information (in the form of indicators) be used in the societal decision making process for sustainable development? What hierarchies of institutional structures, both formal and informal, governmental and non governmental, are required to develop appropriate management regimes, and legislative and enforcement measures which can achieve these goals.

The thesis focuses on aquaculture, a natural-resource dependent economic sector, set in the context of rapid growth over the last two decades, concern over the reported negative impacts which this expansion has brought, and the perception of considerable potential for future development, as discussed earlier. The specific problem addressed is that of assessing the viability and sustainability of individual production processes, or types of process, and in particular on the issue of methods of appraisal and indicators which can be applied to the analysis. While this requires considerations of scale, systems boundaries, and decision making and resource management regimes, these aspects are not a major objective.

The following chapters in this section focus first on the broad requirements of the assessment process, building on the themes raised above, and second, on the system interactions of aquaculture developments, and potential categories of indicators by which these interactions can be assessed.

Chapter 3

Assessing sustainability

Chapter 3 Assessing sustainability

3.1 Introduction

The imprecise nature of the sustainability concept, without strictly definable goals or end points, suggests that the quest for more sustainable development is a process of evolution, rather than the achievement of an objectively defined state. This poses significant operational problems for appraisal, which seeks to evaluate the potential outcome of alternative resource allocation and management options and provide a basis on which decisions can be made, in this case focusing on aquaculture developments. The aim of this chapter is to set the context for assessing sustainability and for analysing interactions between aquaculture systems and their external environment. The specific objective are to:

- highlight key themes of sustainability which must be recognised in developing an approach to assessment.

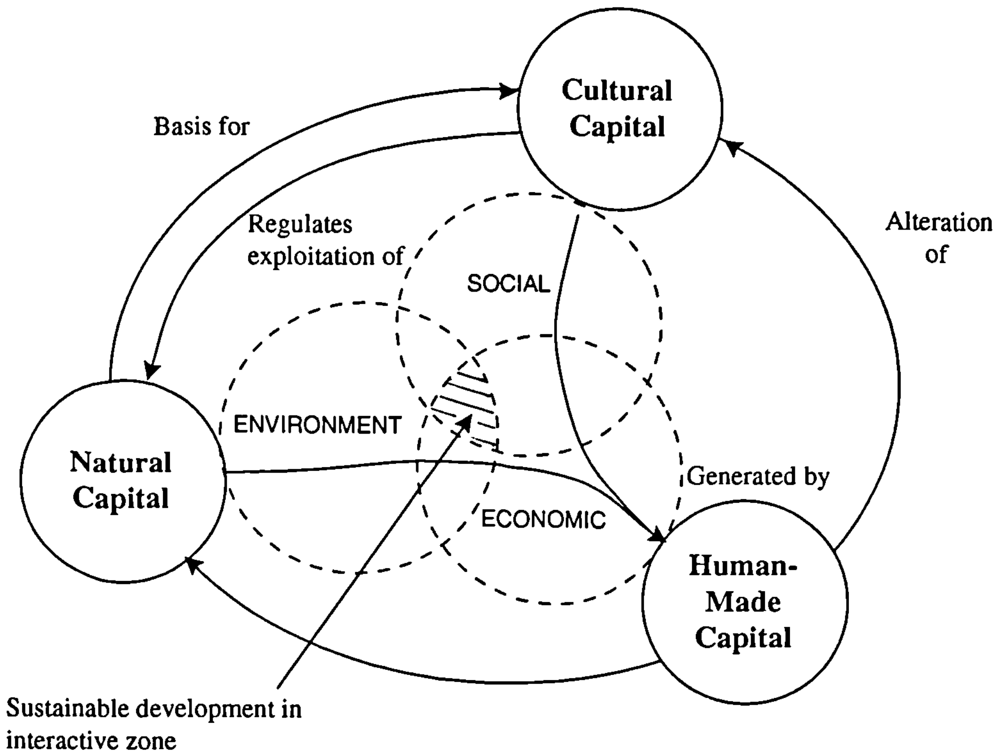
- present an overview on indicators for sustainable development.

- present an overview of the nature of systems, and the potential role of soft and hard systems approaches to problem solving in relation to sustainability

3.2 Key sustainability themes for the assessment process

It was suggested earlier that human activities can be broadly considered in terms of three interacting systems, comprising social, economic and environmental aspects of development, which at any point in time can be considered as forms of "capital" - cultural, human-made and natural. Brought together, these represent stock and activity elements of the same system, as illustrated in Figure 3.1. The capital "stock" represents the bequest of today for tomorrow. In the present, and at a range of scales, this capital represents the total resource base on which current activities depend, and from which new activities evolve. A framework for assessing sustainability must therefore address the potential objectives of these three subsystems.

Figure 3.1 Capital and activity systems as a focus for sustainability assessment methods



(adapted from Barbier, 1987; Berkes and Folke, 1992)

In any development situation, trade-offs will occur between objectives of sustainability in social, economic and environmental systems, and between short term need and long term goals. While in theory maximised goal achievement might be sought across all three systems (Barbier, 1987), there are significant practical constraints, as discussed earlier. Where goals are unclear, information and valuation systems limited, and uncertainty inherent, a pragmatic approach where "good enough" decisions might be defined may be the only effective action.

Two important features for decision making were associated with participation, and the change in the way that decision making deals with uncertainty. For the former, because there is a wide range of potentially conflicting, but equally valid views of the system, constructive trade-offs can arise from participation of a range of stakeholders in the development process. For the latter, a principal task of assessment must be to judge the level of predictability, risk or uncertainty associated with specific aspects of any development. Where there is true uncertainty, but reasonable cause for concern, there may be a need for more proactive approaches in the social process of decision making. The precautionary approach proposed by Costanza and Cornwell (1992), and the use of more flexible and adaptive resource management regimes (Holling et al., 1994) are relevant here.

In the long term, and at a global level, the evolution of activities must clearly remain within certain sustainability boundaries (for human existence) if elements of the whole are to be sustained. The converse, however, does not necessarily apply: specific elements may not need to be sustained or sustainable for the whole to be sustainable. In this respect, sustainability at a local level may have divergent criteria from those at the wider level: developments which may in the long term not be sustained, may still represent a desirable choice in specific situations. The concepts of weak and strong sustainability can account to some extent for the alternative courses that development might follow, and allow a broad classification of different types of development activity.

The application of sustainability concepts to assessment and decision making requires that information be available on a range of potentially conflicting aspects of any development. Although sustainability concepts do not offer absolute values or specific targets, they may suggest broad issues and directions of change within environmental, economic and social sub-systems, which might be considered desirable or otherwise from a sustainability perspective. Indicators which inform on particular aspects of state, or change in state, related to these broad sub-objectives, might then represent a working substitute for clearly defined sustainability goals. If this is possible, it may be feasible to apply an objective oriented framework (ODA, 1992) for formulating and assessing development. In this case an equivalent system of indicators and means of assessment would be required together with the identification of assumptions, risks and uncertainties (and potential reversibility of impacts) associated with the results of each assessment process. This can be set in the form of a logical framework as follows:

Sustainability objective systems	Indicators	Means of assessment	Assumptions, risks and uncertainties
Economic			
Social			
Environmental			

The potential for conflict between sustainability objectives in these subsystems means that these indicators, and the methods by which they can be measured, limit the ability of the framework approach to provide a complete measure of sustainability: what it may achieve, however, is a more holistic view of the trade-offs involved in alternative options. There follows an overview of current literature on sustainability indicators, as a background for considering issues relating to aquaculture developments. Methods of assessment are analysed further in later chapters.

3.3 Indicators of sustainable development

3.3.1 The choice and use of indicators

To select meaningful indicators for a specific activity, there must be a context - a wider set of indicators or features agreed for sustainable development - and some form of (objective) criteria against which the specific indicators might be assessed. This requires objectives appropriate to a wide range of contexts, at different hierarchical levels, from the process through to the global system. This was a key point recognised by UNCED (1992, para 40.4), as follows:

> "Commonly used indicators such as GNP and measurements of individual resource or pollution flows do not provide adequate indications of sustainability. Methods for assessing interactions between different sectoral environmental, demographic, social and developmental parameters are not sufficiently developed or applied. Indicators of sustainable development need to be developed to provide a solid basis for decision making at all levels and to contribute to a self regulating sustainability of integrated environment and development systems"

Although in many situations, particularly in developing countries, there are problems of availability and management of information, there is "a wealth of data and information that could be used for the management of sustainable development" (UNCED 1992, para 40.17). The drawback, however, returns again to the elusive nature of the whole concept of sustainability. Slesser et al. (1994) therefore suggests that:

> "one of the reasons for the current interest in ... indicators lies surely in the hope that they will bring greater understanding of both the significance of that concept and of the action required to achieve it"

There is a limited, but growing literature on indicators. At the international level UNSTAT (1993) proposed a framework in which 12 "clusters" of indicators were identified (Table 3.1). Other examples of proposed indicators at this level include environmental indicators of OECD (1993), and UNDP (1993) indicators of human development. Table 3.2 presents a list of potential indicators broadly covering all three sustainability systems (in which the environment system is divided into resource use and ecological systems): Dalal-Clayton (1993) echoing the comments of Slesser et al., suggests that these can provide a starting point, in that they "give a flavour of what sustainability would look like".

At a regional and national level, there have been a number of initiatives (NEF, 1994a&b), including the proposed indicators for EC comparisons, EC programme and project indicators, and a number of national government and NGO activities (eg Table 3.3). There have also been efforts to develop indicators for application at local levels (eg local government sustainability indicators: LGMB, 1994). These preliminary frameworks show that there is a vast range of potential indicators to be applied in assessing sustainability in the global system, ranging from the wider context above, to specific activity systems (considered later in the context of aquaculture case studies). An example of the potential scale of application of indicators at a national level is presented in the Natural Capital Accounting model (the Evaluation of Capital Creation Options, or ECCO model) developed by Slesser et al. (1994): in this there are 1874 non monetary indicators, and options for additional indicators as required by model users.

From the diverse range of frameworks and indicators proposed, there appears to emerge broad areas of agreement on the types of indicators to be developed. However, there is far less consensus on the specific details. A definitive list of indicators may not be attainable, nor perhaps should it be: the complexity of the systems involved suggest that adaptation and evolution is likely to be an important aspect of sustainable resource management, requiring similar adaptation and evolution of indicators.

In the context of this analysis, concerned with assessing a specific technological sector, the selection of appropriate indicators might then need to be part of the assessment process itself. Such an approach has been presented in the pressure-state-response framework of OECD (1993), outlined in Table 3.4.

Table 3.1 Proposed Framework and list of Indicators of UNSTAT, 1993

AGENDA 21 CLUSTER / STATISTICAL CLUSTER	NAME OF INDICATORS OR INDICATOR GROUPS
ATMOSPHERE	Nitrogen oxides, carbon monoxide and sulphur dioxide emissions in urban areas; Greenhouse gas emissions; Consumption of ozone destroying substances (all tonnes/yr).
Outdoor air quality	Air quality index for urban areas
WATER Fresh water	Industrial / municipal discharges into fresh water bodies(tn/m3) Dissolved oxygen in major rivers (mg/l); BOD, COD; Average annual concentration of phosphorous and nitrogen in major rivers (ug/l)
Marine water pollution	Industrial/ municipal discharges to coastal waters (tn/m3)
Water treatment/ sanitation	Waste water treatment(%) Access to safe drinking water and sanitation services (%) water quality index by fresh water body
LAND/SOIL USE AND QUALITY	Land use changes (km2); Use of fertilisers (tn/km2); Use of agricultural pesticides(tn/km2); Areas of soil erosion (km2); Desertified Areas (km2) Protected area (km2)
BIOLOGICAL RESOURCES	Threatened species (%); Deforestation rate (km2) Forest area regenerated and harvested (km2)
MINERAL RESOURCES Energy Other mineral resources	Total per capital primary energy use (joules, oil equivalents etc) Lifetime of energy reserves (years) Depletion/ depreciation of energy and other mineral resources (%,$)
HUMAN SETTLEMENTS	Municipal waste disposal (tns); Recycling (tns); Noise in dwelling area (no.) Area and population in marginal settlements (km2, no.)
POPULATION, HEALTH AND WELFARE	Population density and distribution (no.); Incidence of environmentally related diseases (no.); Ecological refugees (no.); Infant mortality rate (no. per 1000 live births); People in absolute poverty (no. %); Adult literacy (%)
HEALTH OF ECOSYSTEM	Ecological indicators (%, km^2, etc) Ecological vulnerability index
NATURAL DISASTERS	Frequency and effects of natural disasters ($)
ECONOMIC POLICY (trade, production and consumption patters, Economic growth)	Capital accumulation (negative indicator) environmental protection expenditure, Economic vulnerability index (to be developed)
INTERNATIONAL COOPERATION (financial resources, transfer of technology, technical cooperation)	Distribution / allocation of financial mechanisms ($) Participation in international instruments and agreements
SUPPORT (education, training, science, legislation, regulation, participation, information)	National state of the environment report Environmental statistics compendium (year) National sustainable development strategy (year) Environmental and sustainable development NGOs (no.)

(Source: NEF 1994a)

Table 3.2 A few Indicators of Sustainable Development

THE USE OF ENERGY AND RAW MATERIAL

Per capita resource consumption, for a given standard of living, is dropping.

The proportion of non renewable energy usage in primary production is diminishing, while renewable sources, such as solar or human energy, are increasing: and sectors using non-renewable forms of energy are investing significantly to develop and apply technologies that will use renewable forms.

Passenger km travelled by public transport are increasing in proportion to private motorised transport.

There is a progressive increase in both official incentives to use renewable energy and disincentives to use non-renewable forms.

There is an increasingly free flow of technology, especially to poor countries.

ECOLOGICAL PROCESSES AND BIOLOGICAL WEALTH

Development activities seek to maintain ecological processes (soil fertility, waste assimilation, water and nutrient recycling) and not to exceed the capacity of these processes.

Development increasingly depends upon and conserves a growing range of genetic material, not only the different species but the varieties within species.

Renewable resources are increasingly used and harvested at rates within their natural capacity for renewal.

More and more areas of high value for their irreplaceable environmental services are not only being set aside, but are being effectively managed, with secure funding.

POLICY, ECONOMICS AND INSTITUTIONS

Economies - especially those that depend upon high-volume natural resources data - are diversifying, especially towards high-value information and service industries.

There are growing numbers of formal mechanisms to integrate environmental and development concerns, and to insert environmental values in prevailing systems of economic policy, planning and accounting.

More accurate and representative economic indicators are being introduced to measure sustainable development, so that the currently dominant concerns of consumption, savings, investment and government expenditures are increasingly joined by measures of natural resource productivity and scarcity.

More methods are being introduced for valuing use by future generations, for comparing such use to today's needs and for making equitable trade-offs between generations.

(continued over)

(Source, Holmberg et al, 1991: in Dalal-Clayton, 1994)

Table 3.2 (Continued)

POLICY, ECONOMICS AND INSTITUTIONS (continued)

Flows of resources to and from a given country are increasingly stable and equitable, and do not result in severe net depletion of the natural resource base.

Both the incidence and the effects of "boom" and "bust" are diminishing.

There are both regulatory measure that ensure that resource limits are not exceeded, and enabling measures that encourage voluntary improvements in technology to make more sustainable use of resources within those limits.

Environmental monitoring is regularly and effectively carried out, and both policies and operations are adjusted to suit.

Military budgets are decreasing in relation to budgets for work to ensure environmental security and sustainable development.

SOCIETY AND CULTURE

The notion of resource limits, and the need for sustainability in production and livelihood systems, is increasingly prevalent in a societies values, embodied in its constitutions and inherent in its educational systems.

The community is becoming more diverse in terms of skills and enterprises, and yet remains coherent as a community.

There is a growing body of commonly held knowledge and available technology for maintaining a good quality of life through sustainable activities.

There is a tendency towards full employment, good job security and household stability.

Increasing numbers of people have access to land adequate for sustaining good nutrition and shelter for their families and / or adequate, reliable incomes to pay for these necessities.

The costs and benefits of resource use and environmental conservation are more equitably distributed: consumers increasingly choose to pay for goods and services that are resource-efficient and minimize environmental degradation.

Conflicts over land and resource rights are diminishing.

People who once relied upon unsustainable activities for their livelihood are being supported in their transition to sustainable activities.

Development is increasing the people's control over their lives, the range of choices open to them and the knowledge to make the right choices: it is compatible with the culture and values of the people affected by it, and contributes to community identity.

Table 3.3 Policy Orientated Indices Suggested by Earthwatch

Net resource product Measure of sustainable use of renewable resources.	**Environmental capital** Measure of the status of a nation's environmental and resource capital.
Global environmental capital Measure of each country's contribution to major global environmental issues and the GLOBAL ECOLOGICAL FOOTPRINT.	**National Environmental Impact** Measure of the impact of a country on its own environment.
Individual Environmental Impact The measure of each persons impact within a country, sub-region.	**Net International Product** Measure of economic, resource and environmental contribution of a country's activities to the rest of the world.
Industrial Efficiency Measure of the movement of industry towards sustainability.	**Social Equity** Measure of progress towards meeting some of the principal social goals of UNCED.
Intergenerational Equity Measure of environment and development impacts on human generations.	**Human Welfare** Development of UNDP's Human Development Index to become a more complete measure of welfare.
Capacity building Measures of success in capacity building, particularly with regard to education.	

(Source NEF, 1994a)

Table 3.4 Pressure- state - response (PSR) framework of OECD, 1993

The PSR framework for indicator development is based on the concept of causality:

- Human activities exert a pressure on the environment
- These pressures change the quality of the environment and the quality of natural resources (the "state" of the environment).
- Society responds to these changes through environmental, general economic, and sectoral policies (the "societal response").
- Societal responses then form a feedback loop to pressure through human activities.

Indicators may be developed for each phase in the framework

(Source NEF, 1994a)

3.3.2 The use of indicators

In addition to the problems of identification of suitable indicators, their application in achieving change remains largely unresolved. NEF (1994a) identified three fundamental conditions for achieving shifts in the way that social and economic processes are assessed:

- a need for political will.
- the possibility of overcoming, or at least coping with technical problems if that will is present.
- a clear link between the selected indicators and policy decisions.

They also note a number concerns regarding present efforts towards developing indicators, as follows:

- relatively little work on indicators in key areas, such as consumption, trade, participation and international "footprint" of national activities.
- most of the work is being done in industrialised countries with little emphasis on the problems of the south.
- little or no effort to ensure a wide public participation in the development of indicators.
- a lack of integration between the frameworks and policy targets and objectives.

The context of higher level indicators and criteria for the pursuit of sustainable development (at national and international levels) does not yet exist in any practical sense. This will therefore limit the extent to which individual level assessments can measurably fulfil wider sustainable development objectives.

However, there is still the capacity to examine issues in a local and sectoral context, specifying features of systems in relation to broad concepts of sustainability, and to identify at least some aspects which might be acted on at this level, irrespective of the wider framework. Indeed, it could be argued that this process applied at the activity level, while itself insufficient, is an essential element of identifying the implications of any higher level policy developments which may occur in the future: this will consequently be important in the formulation of workable future policies.

In this context the typology of indicators suggested by Holmberg (1991: in Dalal-Clayton, 1993) may help to clarify the issues involved, separating environmental, sustainability and sustainable development indicators as follows:

- environmental indicators - measuring changes in the state of the environment.

- sustainability indicators- measuring the distance between that change and a sustainable state of the environment.

- sustainable development indicators- measuring progress towards the broader goal of sustainable development at different levels (eg see Table 3.2).

Viewed in the widest sense of "environment", indicators of the first category could include those for economic, social and physical states. The latter two categories are objective related, which therefore require specification of sustainability states and objectives. As suggested earlier, these are rather elusive goals, but still offer the capacity for defining the desirable direction of change in state. Potential indicators for assessing aquaculture developments are considered in the following chapter.

3.4 Sustainability assessment as a systems problem

3.4.1 Introduction

It has been suggested earlier that sustainability must be seen as a systems concept, recognising the complex and evolving nature of real world systems, with the widest boundaries for analysis set at global level. However, an operational approach to the assessment of resource use options must operate at much lower system levels. The problem is therefore one of defining appropriate system boundaries for specific assessments. Before considering systems interactions in the context of aquaculture development, it is useful to outline the nature of systems, to describe systems approaches to problem solving, and consider how these might relate to assessing sustainability.

3.4.2 General features of systems

The origin of systems approaches

In trying to understand the world, western science has generally developed through specialisation and disaggregation, reducing problems into simplified models in which component parts can be described and understood. While this has generated many of the technological advances of human society, it may fail to fully explain the real world, as it must assume that the process of separation does not affect the operation of the parts so divided. The central concept of 'systems' acknowledges that this is not always the case, and embodies the idea of "a set of elements connected together which form a whole, this showing properties which are properties of the whole rather than properties of its component parts" (Checkland, 1984).

Systems approaches to understanding complexities of real world can be seen as the study of a dynamic and evolving framework, into which specialist areas of knowledge come together, and the study of how this framework behaves as a whole. According to Checkland (1984) five classes of systems can be identified and include:

- natural systems (origin: universe and evolution -atoms -planets).
- human activity systems (origin: human self-consciousness -political structures).
- designed physical systems (origin: humans and purpose -machines).
- designed abstract systems (origin: humans and purpose -mathematics).
- transcendental systems (systems beyond knowledge).

Tackling the problems of sustainability of the global system can be seen to comprise the interactions of the first three of these systems, in which the fourth is an important element of the activities of the second and third. The features of systems comprise three basic elements:

- emergence: there are properties at a given level of complexity which can not be explained solely by reference to properties at lower levels of complexity (subsystems).
- hierarchical control: higher levels of systems exert controls over lower level systems.
- communication: material, energy and information -between higher and lower levels, in the form of information from lower to higher levels and feedbacks.

The process of modelling systems can be considered as follows:

- identification of coherent elements of the system, and the definition of the principles of coherence.
- identification of the control mechanisms by which the system maintains its coherence, and the value ranges within which these operate.
- delineation of the system boundary.
- identification of any subsystems of the system, or super-systems.

Hard and soft systems

One of the main origins of systems approaches was in engineering, for defining problem solving sequences in the development and management of complex engineered processes. Known as hard systems approaches, these start with the acceptance of objectives, problem specification and organisational needs. The aim is to provide a solution to a defined problem in the terms in which the problem is posed, so these factors are taken as given. They are characterised by the formulation of the system in terms of quantifiable relationships between component parts, in which communication and control (feedbacks) are deterministic and can be mathematically described. Such approaches are used in both abstract and physical designed systems, and are central to the development of complex human technologies. They have also been applied to biological processes and ecological systems. One of the features of natural systems is that the higher the level of the system, the more complex and variable and the less predictable it is. Therefore predicting the effects of changes to biological systems, and ecosystems, using hard systems modelling becomes less and less certain as the scale increases.

Defining which factors are significant, and how they affect the system is a major problem in complex system modelling. Data is often messy, and incomplete. Problems also arise because effects of change in factors in the system are often non-linear, change in nature near thresholds, and may be subject to delays. Such problems are particularly important when considering impacts of human activity on ecosystems, where rates of change associated with impacts exhibit thresholds or delays which are not apparent until major transitions in state have been triggered. The problem of decision making in such uncertainty has been considered earlier. Attempts to apply hard systems approaches to model the behaviour of social systems encounter even greater difficulties, largely due to the lack of clearly defined problems, and hence objectives, on which to base the analysis:

unlike physical and biological systems, where the laws of physics and natural system behaviour might be applied, social sciences do not lend themselves to such laws (Clayton and Radcliffe, 1992). These weaknesses in hard systems approaches for dealing with ill-structured problems of the real world have led to the development of soft systems approaches. These are more general, concerned with poorly defined problems, providing a contributory role to problem solving rather than being goal directed. A particular feature of social systems (or human activity systems) is that while all systems depend on communication of information, social systems depend on an even more complex phenomenon, communication of meaning (Clayton and Radcliffe, 1992).

Checkland (1984) considers that human activity systems are "always multi-valued, with many relevant and often conflicting values to be explored. The outcome is never an optimal solution, it is rather a learning which leads to a decision to take certain actions, in the knowledge that this will in general lead not to 'the problem' being now 'solved' but to a new situation in which the whole process can begin again". He goes on to propose that such systems can be described in terms of a root definition, in terms of transformations (of inputs to outputs); ownership of the system; actors in the system; customers of the system; environmental constraints on the system, and weltanschauung (world view or context within which events are given meaning), which influences the way people understand their options and make their choices. An overview of the features of hard and soft systems is presented in Table 3.5.

3.4.3 Applications of systems approaches to sustainability.

The problem of all methods of assessment used to help understand interactions at different systems levels, from global models to single activities, is that the simplification involved can not fully describe and predict real world systems. This is particularly pronounced when analysing societal systems, and the values and contexts for development. Many of the features of sustainability described earlier are those of a soft system, where there are never totally clear cut answers to any specific decision, but simply an ongoing process of resource management, and economic and social change. As such, hard systems approaches, in which problems are reduced to definable sets of interactions and outcomes, will not alone provide a sustainability "solution".

Table 3.5 The 'hard' (systematic) and 'soft' (systemic) traditions of thinking compared

The 'hard' systems thinking of the 1950s and 1960s	**The soft systems thinking of for the 1980s and 1990s**
PRINCIPLES	
• Oriented to goal seeking. • Assumes the world contains systems which can be 'engineered'. • Assumes systems models to be models for the world (ontologies). • Talks the language of 'problems' and 'solutions'. • Terms in which problem is posed taken as given.	• Oriented to learning. • Deals with poorly defined problems. • Assumes the world is problematic but can be explored by using system models. • Assumes system models to be intellectual constructs (epistemologies). • Talks the language of 'issues' and 'accommodations'. • Contributes to problem solving rather than being goal directed.
SEQUENCES	
eg: • problem definition: what is needed. • choice of objectives: decide what would be required to reach each objective, and formulate measures of effectiveness. • systems synthesis: identify the various possible alternative systems. • systems analysis: analyze and evaluate the various hypothetical systems in the light of the objectives. • system development. • current engineering: realisation of the system, monitoring, and feedback to modify the system.	eg • express unstructured problem situation. • definitions of relevant systems. • building of conceptual models. • comparison of models with expressed situation. • effecting feasible and desirable changes. • action to improve the problem situation. • re-examine unstructured problem situation. ....
ADVANTAGES	
Allows the use of powerful techniques. Useful for highly defined problems.	Is available to both problem owners and professional practitioners. Keeps in touch with the human content of problem situations.
DISADVANTAGES	
May need professional practitioners. May lose touch with aspects beyond the logic of the problem situation.	Does not produce final answers. Accepts that enquiry is never-ending.

(adapted from Checkland, 1984 & 1985)

However, this is not to suggest that hard systems approaches and reductionist science do not have a role. Indeed, for many system elements they are the only tangible tools available to provide information on which decisions can be made: it is through the application of hard systems methodologies that many soft systems problems are given shape. What has to be noted is that these tools have limitations: firstly, they are only as good as the information used to determine relationships within the system, and the valid domain of analysis may be limited. Further, information used and assumptions made may by design or default, fulfil the preconceptions of the analyst, or the specific objectives of particular stakeholders (also applies to soft system approaches). As Clarke (1994) observes "sustainability is often treated as something to be attained by quantitative assessments, technological improvements, and whatever behavioural adjustments are needed to bring people back to sustainability ...... people place too great an emphasis on the first two, ignoring the reasons for their current 'misbehaviours' ".

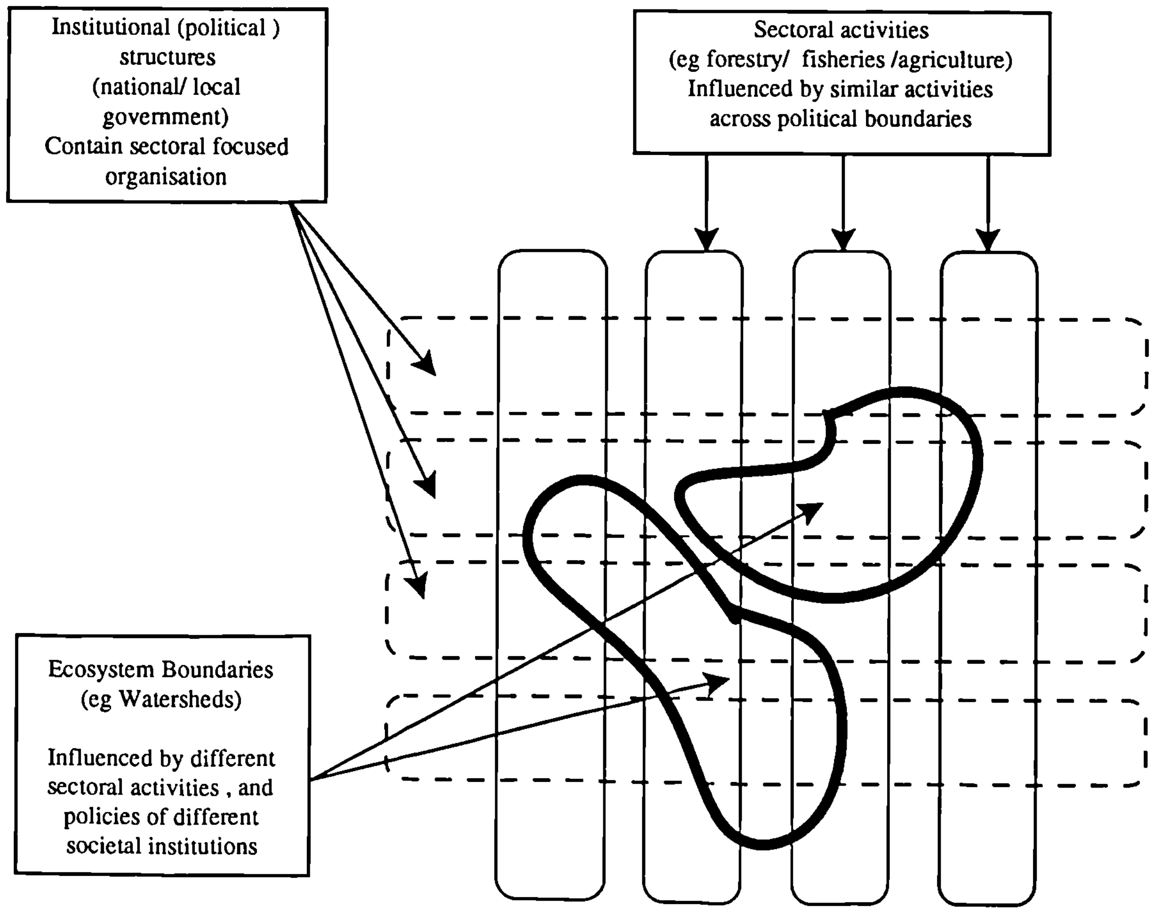
The question for the soft systems approach is how available tools are selected and used in the decision making process. In this context, taking a systems approach is a way of organising thinking, describing a problem, and requires active participation of a range of stakeholders with the diversity of views which are legitimate elements of sustainability assessment and the decision making process. To some extent this is simply a way of formalising existing processes into conceptual models in which connections, feedbacks, roles and value judgements can be presented more explicitly. The ongoing nature of the soft systems framework also applies, in increasing learning, re-evaluation, redefining of issues and problems, and adaptation. Within this, pragmatic judgements are required, using established, if sometimes limited and uncertain methods, to make hard decisions.

The establishment of system boundaries is a critical process for simplifying reality to provide a framework for specific analyses. These boundaries need to be set so that major issues are not overlooked, but that the process is not complicated by too much information, which may make it unnecessarily complex and costly. Current approaches tend to focus on sectoral activities, set within the structure of social/political systems. It could be argued these human activity boundaries are often in conflict with boundaries of natural systems: that decisions made on a framework of analysis within these boundaries may not be effective unless existing natural boundaries are also recognised (Figure 3.2). Thus a systems approach to assessing sustainability of an aquaculture development would require analysis to include interactions with associated natural and human systems, within appropriate boundaries. This is increasingly recognised in resource management systems based on boundaries such as watersheds, or in the development of integrated coastal resources management plans.

Therefore while an analysis for specific aquaculture technologies may identify certain characteristics which are more or less likely to be sustainable, it will not be possible to determine this clearly unless analysis is carried out for associated and higher level systems. The objective of the following chapter is therefore to outline the main features of interactions of aquaculture systems and this wider environment, to provide the basis for analysing specific development case studies, and for wider analysis of appraisal methods presented later.

Figure 3.2 Societal and ecosystem boundaries

Resource management and production systems are often in conflict with natural systems



Chapter 4

The interactions of aquaculture systems and their environment

Chapter 4 The interactions of aquaculture systems and their environment

4.1 Classification of systems and impacts

The prospect of increasing aquaculture production into the next century implies increasing environmental impacts. "Environment" has been broadly defined as "the conditions, circumstances and influences under which an organisation or system exists. It may be affected or described by physical, chemical and biological features, both natural and man-made. *The* environment is commonly used to refer to the circumstances in which man lives" (Brackley, 1988, in Winpenny, 1991). The environmental impacts of an activity can therefore relate to both ecological and societal changes resulting, and can be desirable or undesirable from the human perspective.

Impacts can be generated by the requirements for inputs, and the production of outputs. In aquaculture literature, environmental impact is often defined more narrowly, in terms of physical and biological changes occurring at the site of operation. Wider effects include the import of renewable and non renewable resources from other systems, often in the form of manufactured products. If these local and wider changes in resource use are considered as primary and secondary impacts respectively, then associated social and economic changes, such as the provision or loss of livelihoods, the production of food, or the loss of amenity, can be considered as tertiary impacts (Figure 4.1).

Classification of aquaculture systems according to the level and type of environmental impact can be made on three principal criteria, illustrated in Figure 4.2. These include land or aquatic substrate required (eg seabed area), whether the production system is a net importer or exporter of nutrients, and the amount of water exchange required. In all cases, increasing intensity reduces the land or substrate area required, but increases the need for water exchange. Intensive fish and crustacean systems require large imports in the form of feeds, and export large amounts of nutrients to the surrounding ecosystem. Increasing intensity is also characterised by increasing use of chemicals and pharmaceuticals, and increasing use of fossil fuel energy.

Figure 4.1 Classification of Impacts of aquaculture developments

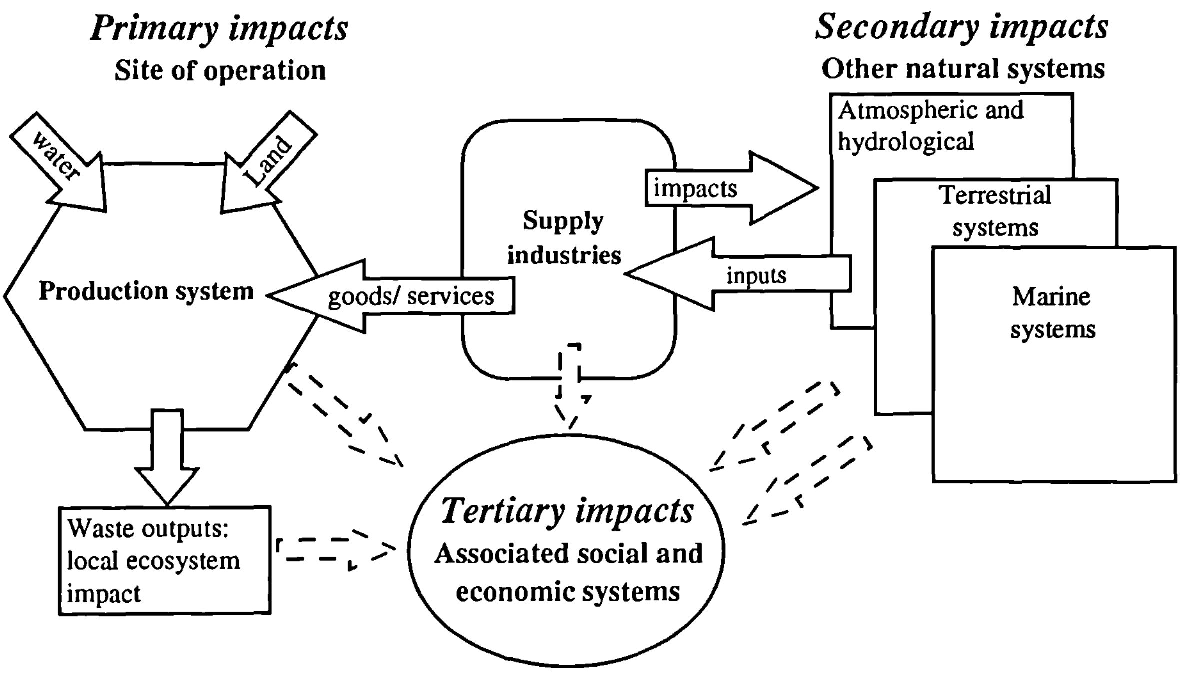
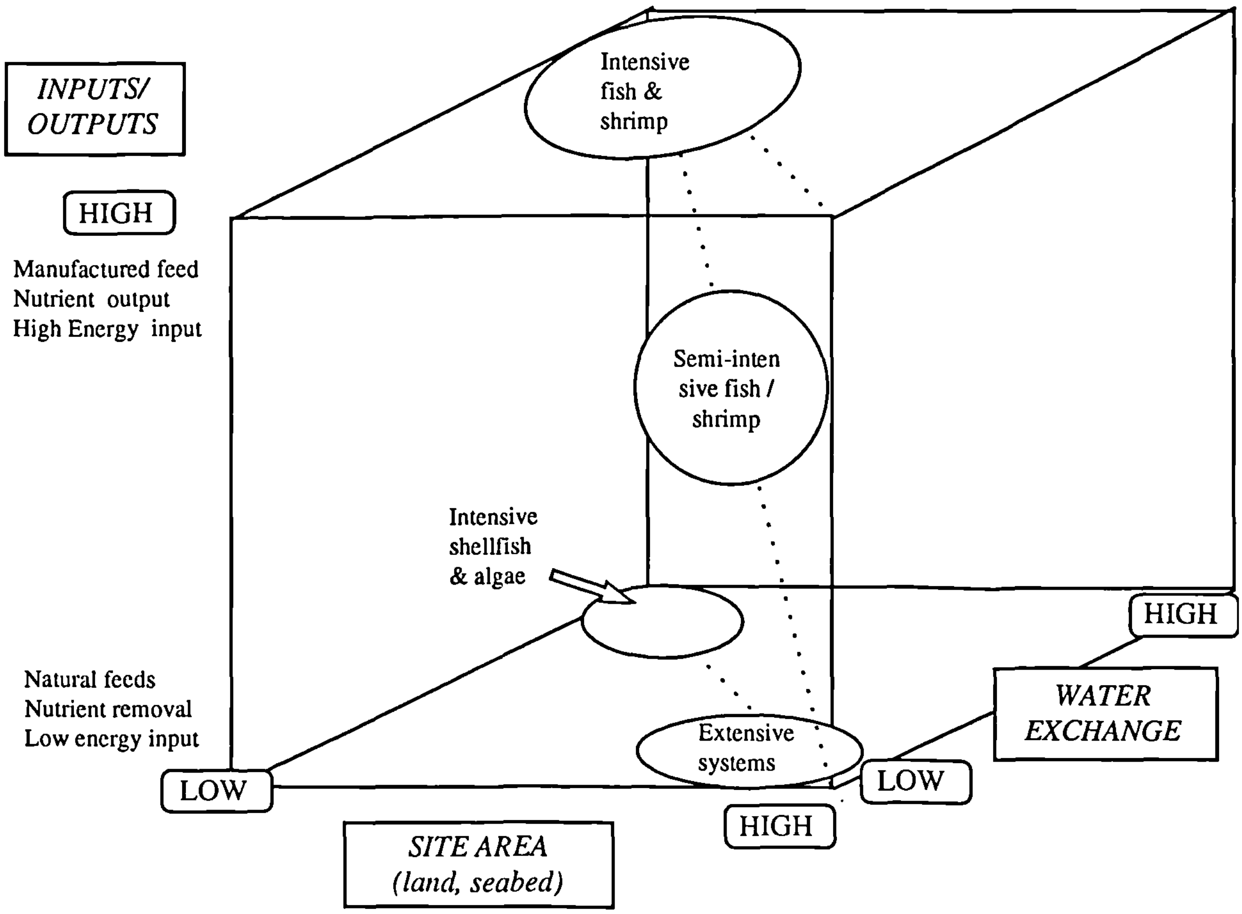


Figure 4.2 Classification of aquaculture systems according to land, water, and other resource flows



4.2 An overview of impacts of aquaculture systems

4.2.1 Introduction

Impacts may occur at a range of scales, in both space and time, and may not be readily apparent, or only become obvious with hindsight and more information. However, a growing volume of literature documenting impacts of aquaculture development can be used to help define issues of potential relevance to sustainability assessment. The aim here is to presents an overview of this literature, focusing on primary and secondary impacts, with reference to social and economic effects where appropriate (here concerned primarily with negative effects, which are most often neglected in the development process). For reviews of the main issues see Beveridge (1984); Gowan and Bradbury (1987); GESAMP (1991); Makinen (1991); Barg (1992); Pillay (1992); Pullin et al. (1993).

4.2.2 Site requirements

Site impacts of land based systems

The most important site related impacts of aquaculture developments are related to the clearing of wetlands (coastal, estuarine and fresh water), which are recognised as amongst the most productive ecosystems in the world (Kusler et al., 1994). The values of such ecosystems have only recently started to become recognised, and include both direct and indirect values in the form of goods and services, in addition to being systems of high biological diversity, holding potential future values of as yet unknown goods services (Odum, 1989; Folke, 1990 and 1991). This is not necessarily to suggest that all wetlands should be preserved, but that in the past their real value may not always have been included when assessing costs and benefits of development. While limited clearing of such ecosystems may have little overall impact, large scale development may have had very significant effects.

The best documented examples are associated with shrimp farm developments throughout the tropics, some of which have resulted in substantial clearing of mangrove. In Thailand, shrimp farm developments accounted for about 38% of the mangrove removed between 1979 and 1986, representing 13% of the total resource of 1979 (Phillips et al, 1993). The values to society of these resources, both direct and indirect, were not accounted for in this development process. These have been documented by a number of authors (Bailey, 1988; Ruitenbeek, 1991; Primavera, 1991; Pullin et al, 1993; Ruitenbeek and Cartier, 1993) and include local factors such as coastal protection, waste assimilation, water purification, and a range of subsistence level activities for rural populations (such as foods, medicinal materials, fuel wood, building materials), to more distant impacts on fisheries recruitment, through destruction of nursery grounds. Impacts have also been felt by the shrimp farming industry itself, as many operations rely on wild populations for stocks.

The use of agricultural land for aquaculture is less controversial. In simple terms, where privately owned, land converted to aquaculture may not be a problem if the development meets the owners objectives (commercial or otherwise) better than alternative uses. In most cases aquaculture does not cause irreversible changes in the land (Pillay, 1992), and therefore does not limit future potential uses, or even adjacent land users. There are, however, exceptions, such as some pump ashore coastal systems for shrimp culture. Salination of the soils, due to seepage of sea water from ponds, or infiltration of saline waters due to water table reductions, has rendered not only the pond area, but also the adjacent land, unsuitable for agriculture. This produces not only hidden future costs in terms of land degradation, but also immediate costs to neighbouring farmers.

Site impacts of water based systems

Water based systems rely on structures to enclose (eg cages, pens) or support (mussel or seaweed lines) the cultured organism. Impacts are generally related to the physical structures, which will limit access by other users. There may also be problems of restriction of water flow and resulting sedimentation, documented in particular for shellfish culture systems (Pillay, 1992). The area of seabed occupied by intensive cage based fish farming is relatively small, and in general probably do not represent a major impact on other users. However, due to the requirement for sheltered sites, use conflicts, such as the obstruction of safe anchorages for leisure and fishing craft can arise. It was estimated in 1988 that 15 -20% of the best anchorages on the west coast of Scotland were occupied by fish farm developments (Pepper, 1988). In addition to the loss of productive or functional use values which may arise from aquaculture site developments, aesthetic and other intangible impacts may occur. These may represent changes in uncosted 'quality of life' values of local people, but may also generate economic impacts through the disruption of income generating activities associated with these features: for example, in Scotland, the "unspoilt scenery, peace and quiet" are major attractions to tourists, who contribute significantly to the Scottish economy (Pepper, 1988). To date, these aspects are rarely explicitly valued within development policy and planning, and often represent an area of considerable controversy. However, in Scotland there are guidelines for siting and management to reduce such impacts (CRC, 1987), and the official view, expressed in a Government blue paper on fish farming in the UK (HCACR, 1990), although acknowledging the scenic impact, considers that "with sensitive planning, developments can be accommodated without spoiling enjoyment of the.... amenity of others".

4.2.3 Water requirement

The water requirements of aquaculture systems increase with the level of intensity. Extensive systems, based on maintaining nutrient levels to stimulate natural productivity, only require water supply to fill the pond, to compensate for evaporation and seepage losses, and in some cases to flush out leachates (eg in areas of acid sulphate soils). While there is potential for conflict where water resources are scarce (eg Zambia, Harrison, 1993; Israel, Hepher, 1985), in many countries (eg Bangladesh, Sri Lanka, India, Israel) traditional fish ponds have served as reservoirs for domestic, agricultural and livestock use (or vice versa) (Muir, 1992). In coastal areas, traditional extensive systems generally rely on tidal exchange and replenishment during spring tides. Intensive systems, whether ponds, tanks or cages, require increasing flows of water to remove wastes and metabolic products, with the potential for extended impact beyond the physical farm boundaries. An overview of the water resource management implications of different types of aquaculture system has been presented by Muir (1992).

For fresh water systems, both surface and ground water supplies are used. Intensive systems using surface waters do not generally have an impact on the quantity of water available, as evaporative and seepage losses are usually small relative to the total flow. The scale of development can be limited by the minimum flow available to supply clean oxygenated water. Such limitations can be overcome by technological solutions in the form of aeration and recycling systems, but these tend to be capital and energy intensive

When ground water is used, due to shortages of surface water, or for reasons of water quality, these requirements can be more significant where the rate of use is greater than that of replacement. In addition to being ultimately unsustainable for the farming operation itself, wider impacts to other users may include problems of availability for domestic and agricultural use, quality, infiltration of saline water, and in extreme cases, land subsidence.

Cage based systems, as for intensive land based systems, do not have an impact on the quantity of water resources, but do require high volumes of exchange (Phillips et al, 1991) and can have significant impacts on resource quality (considered later).

4.2.4 Nutrient, feed and energy requirements

The demand for nutritive inputs, either indirectly through fertilisation to increase productivity of the culture environment, or directly in the form of feedstuffs, increases with the intensity of the system. In extensive fish and crustacean systems, and in most shellfish production, growth is provided by natural productivity. The most intensive systems rely totally on industrial-manufactured feeds, often with a high proportion of fish meal, which in turn relies on the productivity imported from other ecosystems (Folke, 1988). The sustainability of more intensive aquaculture is therefore linked to that of other resource systems, and will affect livelihoods associated with these resources. Greater reliance on imported and processed feeds, and mechanisation also increase demands on non renewable energy sources. The issue of energy use and sustainability is considered later.

4.2.5 Stock requirements

Many aquaculture systems hold stocks to their reproductive stages to provide future generations of stock. However, in some (mainly marine) systems, such as shrimp and milkfish culture, a significant proportion of stock is derived from the natural environment, either through the capture of mature animals, or of juvenile stages (Beveridge et al., 1995). While there is, as yet, lack of direct evidence, this may have a significant impact on the natural productivity of these stocks. There is also evidence of destruction of juveniles of other species as a by-catch of the shrimp larvae fishery, which may have impacts on other commercially important fisheries (Banerjee and Singh, 1993). There are therefore potentially significant social and economic impacts associated with these activities.

4.2.6 Nutrient waste discharges

This issue applies primarily to more intensive, through-flow aquaculture, as more extensive systems rely on retention of nutrient inputs to maintain productivity. (Edwards, 1990, reports that semi-intensive systems retain 80-90% of added nutrients). The effect of high levels of particulate organic matter and dissolved nutrient discharges depends greatly the ability of the surrounding ecosystem to assimilate these wastes. Where water exchange is limited in comparison to the waste loading, eutrophication, and oxygen depletion can occur. This can be important in fresh water bodies and enclosed marine systems, but has also resulted in problems in open coastal zones where many operations discharge into a local area. Such impacts can influence the viability of the farming operation, as well as causing direct and indirect impacts for other users. These impacts are discussed in more detail in a case study in the next section. As noted earlier, extensive culture systems, and shellfish and algae culture, can improve water quality by removing nutrients and organic particulate matter (Inui et al, 1991; Folke and Kautsky, 1992).

4.2.7 Chemicals and drugs

A wide range of chemicals and drugs is used in aquaculture, particularly, but not exclusively, in intensive production. These include compounds such as antifoulants applied to construction materials, and chemotheraputants for disease control. There is particular concern over the use of the latter because of the amounts involved, their ease of entry into the aquatic environment and the lack of knowledge of their effects (Brown, 1989; Brown and Higuera, 1991; Michel and Alderman, 1992; Weston, 1994). Even in countries with strict licensing procedures, the emphasis, until recently, has been on the efficacy of the drug and safety of the consumer, rather than on the environmental effects (Beveridge, 1994), and the potential for wider scale effects on human welfare.

4.2.8 Interactions with wild stocks and wildlife

Concerns over the introduction of cultured organisms include impacts of exotic species on local ecosystem diversity (Ross and Beveridge, 1994); the potential for introduced pathogens to infect wild stocks (Sindermann, 1993); genetic interactions with wild stocks of the farmed species (Maitland, 1987), and the potential for the farming activity to increase conflicts with local wildlife (Beveridge and Ross, 1994) . While all these impacts could potentially represent negative social and economic impacts, there is generally a lack of evidence or means by which these can be assessed.

4.3 Potential indicators of sustainability in aquaculture systems

There is a wide range of aquaculture systems, and a wide range of associated impacts. As discussed earlier, aquaculture is an important economic activity, and can bring considerable benefits to individuals and local communities, through the provision of livelihoods and food, and through generation of export revenue. There are also, however, potential resource use conflicts which have generally been neglected in the rapid growth of some sectors over the last two decades. Due to the apparent diversity of the aquaculture sector, it is unlikely that a standard and definitive set of indicators of sustainability could be developed for application to all systems. However, it is possible to define types of indicators, and the direction of change towards broad sustainability goals, which might be applied to assessing economic, environmental and social aspects of aquaculture developments. These are illustrated in Table 4.1, which serve to summarise the points and issues discussed earlier. Finally, Table 4.2 summarises some of key features of sustainability which may apply to the development of an approach to assessing sustainability of aquaculture development.

Table 4.1 Potential indicators of sustainability in aquaculture developments

System	Indicator class	examples	Direction of change for increasing sustainability
Economic	Financial	profitability	increasing
	Economic	employment- direct/ indirect exports, values	increasing
Environment	Impacts known	-water quality (nutrients, oxygen) -land use change, loss or change of habitat and biodiversity	reducing / minimising impact improving quality and diversity
	Impacts uncertain	-use of chemical and drugs: (with potential for bio accumulation / resistance: potential ecosystem and human health implications)	reduction in use
		-species and genetic variant introductions, disease introductions	reductions in introductions and movement
	Resource use	Non renewable (fossil fuels: related to level of intensity, and source of feed).	increasing efficiency decreasing dependence
		Renewable (related to level of intensity, trophic level of species, source of feed).	increasing efficiency decreasing resource imports increasing integration
Social	Welfare	Nutritional/ income benefits (increasing consumption by/ earnings of / those in need)	Decreasing cost of fish/ accessible to those in need. Activity accessable to those in need
		Community stability (viability of schools, shops, rural economy in general);	Increasing diversity of activity
		Product safety/ quality; Health and safety at work;	Decreasing use of chemicals and drugs
	Equity	Change in wealth distribution, and access to and control of resources	decrease in equity gap; subsistence activities valued in economic assessment
	Rights	Level of participation in decision making*;	Increasing participation particularly local say in local development and resource management.

* Participation, as a component of the assessment and decision making process, may reflect the extent to which trade-offs have included views of different stakeholders.

Table 4.2 Key features of sustainability for the assessment process

- the lack of a clearly defined sustainability goal means that there are unlikely to be clear cut answers to the question of sustainability of specific activities.

- the framework for the assessment must include potentially conflicting sets of objectives in environmental, economic and social systems.

- the process must providing information by which trade-offs between the needs in these systems can be more explicitly incorporated into decision making.

- incorporation of the potentially conflicting views of different stakeholders is central to sustainability assessment, which must therefore aim to be a participatory activity.

- there is a need to take a more precautionary approach in dealing with environmental uncertainty (e.g. impacts of chemicals and pharmaceuticals; introduction of exotic species and genetic variants; the potential for disease transfer; habitat destruction)

- due to the variety of aquaculture systems, and development situations, developing appropriate indicators must be seen as an integral part of the assessment process, although broad guidelines for such indicators can be proposed.

- in the absence of clearly defined goals, indicators of direction of change, relating to the broad concepts of sustainability, may provide the basis for practical action.

SECTION 2

AQUACULTURE DEVELOPMENT CASE STUDIES

SECTION 2 AQUACULTURE DEVELOPMENT CASE STUDIES

INTRODUCTION

The assessment of sustainability of any aquaculture development is likely to require a broad range of specialist disciplines. The requirements of the process may also vary with specific characteristics of different technologies and circumstances of development. Furthermore the interpretation and views of sustainability may vary according to the perspectives of different stakeholders. There are many methods of assessment which are commonly used for project analysis. It is therefore appropriate to examine the extent to which some of these methods could apply to the process of sustainability assessment. This is approached at two levels, in the form of a detailed analysis of case studies here, and a more broad ranging analysis of appraisal methodologies in Section 3.

As pointed out earlier, it is through understanding of the outcome of past developments that insights on impacts and sustainability implications can be derived to assist the process of assessing future developments. The aim here is therefore to provide depth to the analysis by focusing on specific aspects in the context of three case studies, each concerned with a different view on aquaculture development. These are not intended to represent the holistic view required for sustainability, but aim to examine the extent to which particular more traditional forms of assessment may contribute to a more complete approach. Each case is based on the primary requirement of economic or financial viability as a prerequisite for sustainability from the point of view of the producer, and is based on specific areas of study. The three sustainability themes investigated are environmental impacts, resource use assessment (emphasising non renewable resource use) and aspects of aquaculture at the development level, loosely related to the concepts of primary, secondary and tertiary impacts introduced earlier. The focus of each case is as follows:

Chapter 5. Case Study 1: Environmental impacts of intensive trout production
The focus here is specifically on the primary environmental impacts associated with nutrient waste generated by an intensive fish farming operation in Scotland. The perspective of the analysis, set at the level of the business, is primarily concerned with the local environmental interactions and feedbacks to the management process, and the

implications for commercial sustainability. The objective is to analyse the role of indicators of environmental change and production performance in the development of an adaptable management process, and the potential role of impact models in predicting sustainable levels of development (in the context of waste induced impacts).

Chapter 6. Case study 2: Energy valuation as a sustainability indicator

Resource use efficiency is a major theme in the concept of sustainability. This case is focused on the potential application of energy analysis as a method of assessment, and energy as an indicator of sustainability in terms of secondary impacts of aquaculture technologies. The specific emphasis is on assessment in terms of non renewable resource use (fossil fuels), based on a desk study of a range of existing aquaculture production processes. The potential role of energy analysis for renewable resource use assessment is briefly discussed.

Chapter 7. Case study 3: Sustainability at the development level: aquaculture in rural communities.

This case presents an analysis of an externally assisted aquaculture development project in Malawi, the objective of which was to create the basis for a sustainable aquaculture sector in smallholder farming systems. The specific focus is on the process by which the project was assessed and implemented, highlighting a range of limitations associated with the sectoral, technical and economic focus of this process. The outcome of the case study is the proposal of a range of potential indicators on social aspects of development which might be included in the sustainability assessment process for such developments.

Each case considers the potential role of indicators of the particular aspects of the process being examined, and the potential usefulness of the approach in contributing to a more broad ranging process sustainability assessment.

Chapter 5

Case study 1

Environmental impacts of intensive trout production: Sustainability in the producers perspective.

Chapter 5 Case study 1: Environmental impacts of intensive trout production: Sustainability in the producers perspective.

5.1 Introduction

This case study is focused on the environmental interactions of an intensive, cage based, rainbow trout farming operation in Scotland. It was chosen as a good example of a closely linked system, with clear physical boundaries, and significant impacts and feedbacks between the production system and aquatic environment. The work was also based on practical management objectives, of improving production performance, in effect, seeking commercial sustainability. Detailed data were collected from 1982-1987, followed by a review of the system in 1992. The output of this work is described in detail in annual reports provided to the company (Stewart, 1983 - 1987). A large quantity of data was involved, a small proportion of which has been included to illustrate this case study, presented below and in Annex 1. The objectives are to:

- examine the measurement of environmental impact of an intensive aquaculture operation.

- consider how the environmental relationship may be expressed at the level of the business and local impact, and explore feedbacks to the management of the production process.

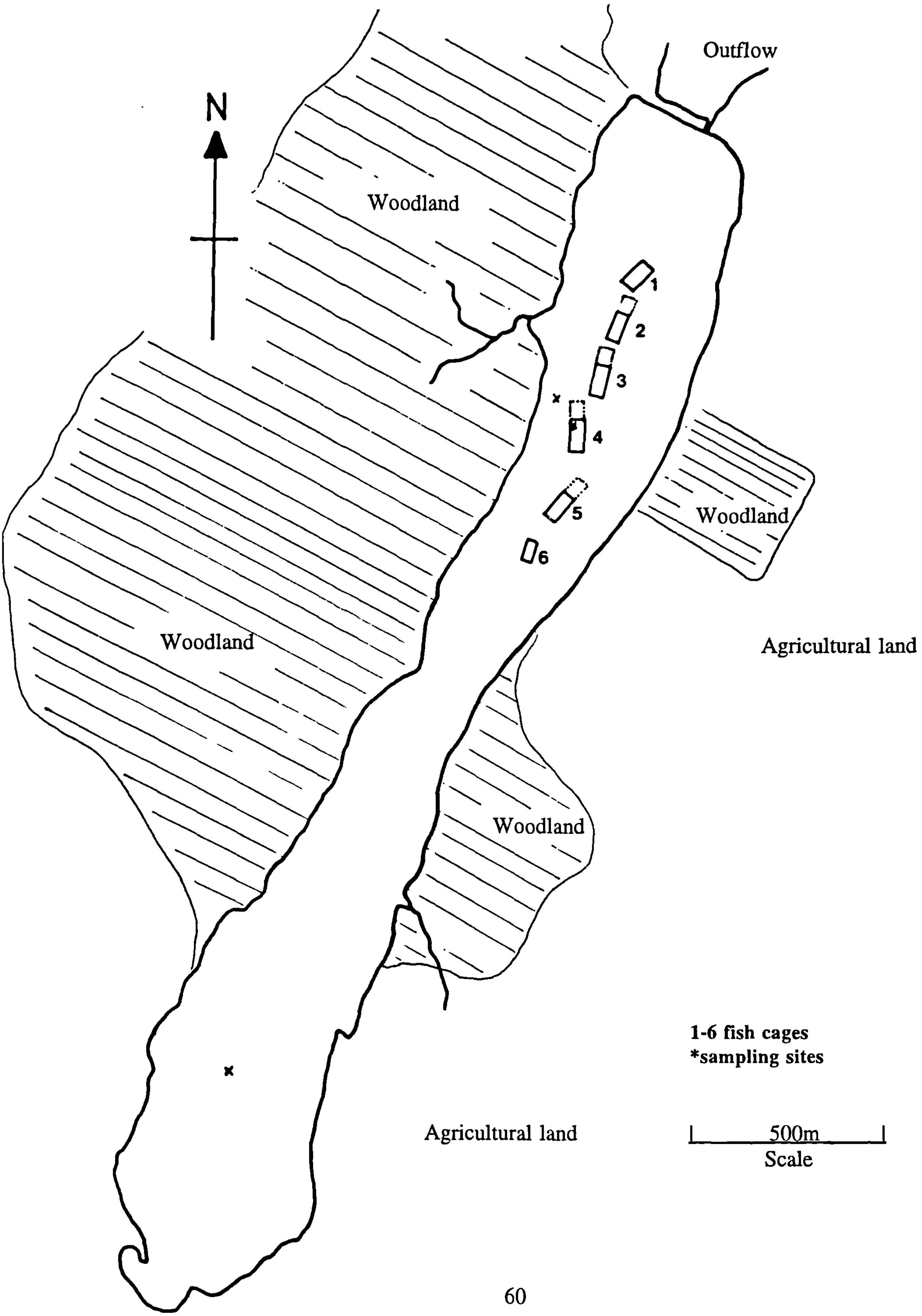
- consider the use of various environmental and production related indicators in the management process.

- consider, in the light of these points, the relevance of environmental modelling, monitoring and management to questions of sustainability.

5.2 Background

The farm is located in a small fresh water loch, on an island on the west coast of Scotland. Loch Fad is 71 ha in area, shallow (average depth 5m, maximum 12m), hyper-eutrophic (since early 1980s), lying on a S.E. to N.W. line along the Highland Boundary Fault (Figure 5.1).

Figure 5.1 Loch Fad



The loch has a dam with a sluice gate at the northern (outflow) end, built to supply water to linen mills in the 18th century. The surrounding land consists of deciduous and coniferous woodland to the north and west, and agricultural land mainly to the south and east. The loch has two major, and a number of minor inflows. The average water retention time is about 6 months. The hydrography, and the dominance of coarse fish species such as pike, perch and roach suggests that this was previously a eutrophic, lowland type loch (Beveridge, 1981). However, based on catchment and land use data, pre fish farm conditions may have been classified as mesotrophic (Bostock, 1987).

The trout farm, established in 1976, was a subsidiary activity of a sea food processing company. It was set up to generate additional revenue and, by using waste from scallop and prawn (Nephrops) processing as feeds, reduce factory waste disposal costs. These wastes were supplemented, and later replaced by commercial feeds as production increased. This was due initially to increasing feed requirement, and later due to the observed fish health problems associated with the use factory wastes. By 1980 annual production had increased to 60 tonnes, rising to 300 tonnes in 1986. In the early 1980s, with a decline in volume of seafoods from the local fishery, the factory depended increasingly on trout processing. Due to limited capacity for increased production in the fresh water site, the company expanded trout production to a seawater site in 1984. This case will focus on the fresh water operation.

In 1980, in response to observed deterioration in the loch's water quality over previous years, a study was commissioned to examine the impact of the fish farm on the aquatic environment (Beveridge, 1981). In 1980 and 1981, further deterioration in the loch environment occurred. Increasing stock losses were attributed to poor water quality, parasites and disease. In response to this, the monitoring and advisory programme on which this case is based was established in early 1982. This is believed to be one of the earliest examples of a full time environmental monitoring of commercial aquaculture.

Data collected over the 5 year period (Stewart, 1983-87) included water quality (daily, weekly and monthly sampling periods), fish health (weekly to monthly), growth performance and stock loss (variable periods). An output of this was the development of stock management and recording procedures to monitor growth performance, feeding and mortalities for all farm stocks, as these were not included in initial collection of management information. These were fully implemented as part of routine management in 1985, providing a more comprehensive picture of the relationship between environmental change and production performance.

The aim is to present key findings relating to the interactions between the fish production system and the farming environment, with the intention of describing the strategic relationship between sustainability and environmental impacts. These are considered both in terms annual cycles and short term changes, and in the context of the apparent longer term trends.

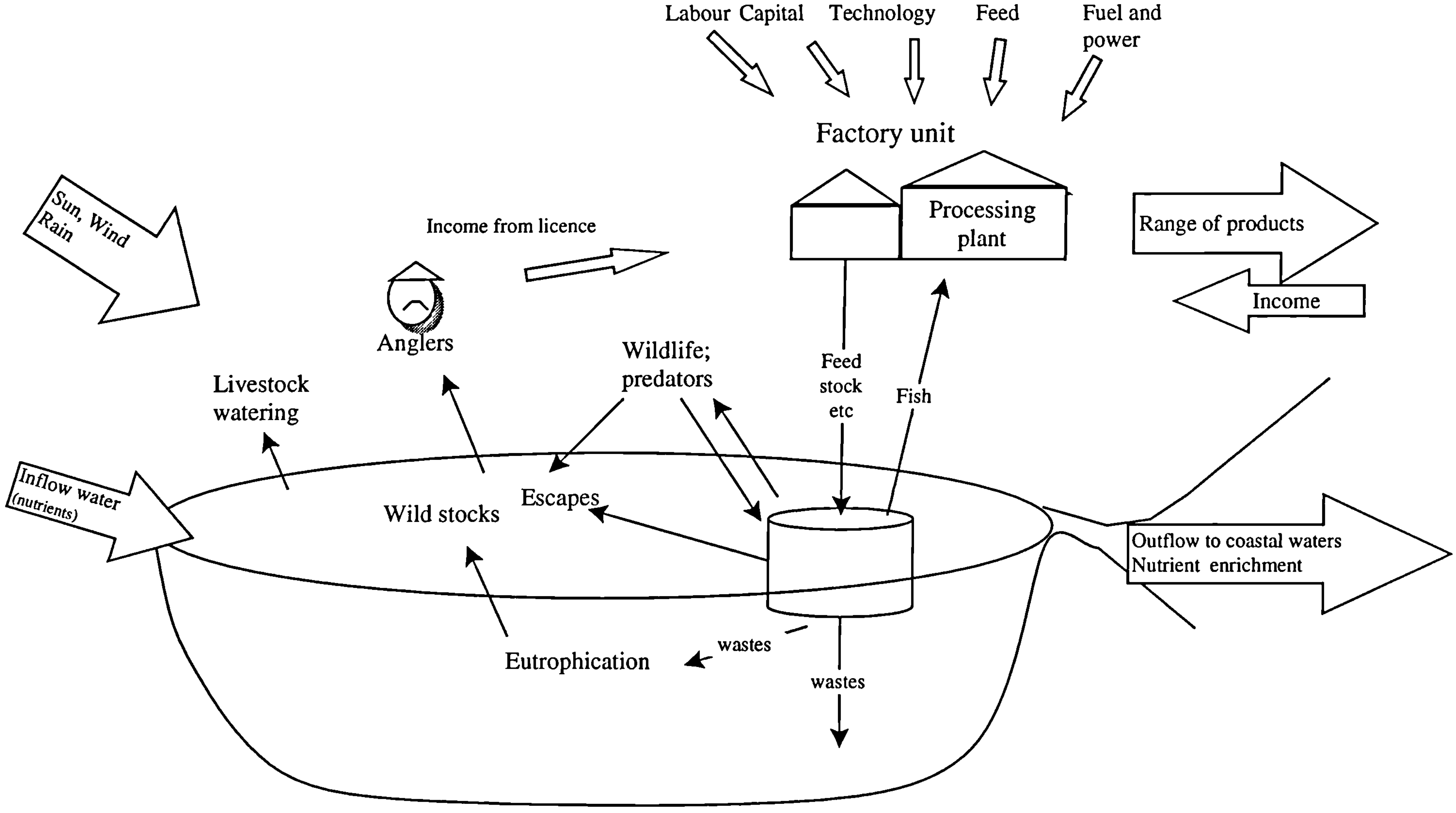
5.3 The system and its indicators

5.3.1 System description

This aquaculture system is illustrated in Figure 5.2, and comprises the fish farming business and the loch ecosystem. The main objective of the fish culture operation, as part of a business system (including a processing factory and later a seawater production site), was commercial sustainability. Inputs to the fish production system included capital equipment, fish feeds, fish stocks, labour, fuel and power. The commercial output was whole trout, transferred to the factory for processing before sale. Other outputs included wastes in form of particulate organic matter and dissolved nutrients from waste feed, fish faeces and metabolic wastes, which entered the loch ecosystem.

The loch ecosystem in which the fish farm was sited provided the necessary physical environment for the fish culture operation, in terms of water quality and shelter, and waste disposal and processing. The loch system was also used by other interests, including livestock of adjacent farms and recreation, primarily anglers. The monitoring programme aimed to improve understanding of interrelationships and feedbacks between these systems, specifically to provide advice on management practice to improve commercial viability and prospects for sustainability. The objective here is to consider interactions both in terms of the commercial sustainability of this particular activity, and the question of sustainability from an ecosystem perspective.

Figure 5.2 The aquaculture system comprising the business system and the loch ecosystem



The choice of data was based on the need to provide indicators of the condition of both the loch environment and the performance of the fish stocks over time, to understand system interactions and develop more commercially sustainable management practices. These are summarised in Table 5.1. The results of the monitoring programme are discussed below.

Table 5.1 Potential indicators for assessing commercial sustainability

INDICATOR CATEGORIES	INDICATORS	OTHER RELEVANT DATA AND INTERACTIONS
Environmental indicators	short, seasonal and long terms trends	
Water quality	(nutrient and oxygen levels, phytoplankton, turbidity, temperature)	relationship between weather conditions and environmental conditions
Stock performance indicators		
Change in stock health Level of mortalities	incidence of disease for different stocks, cohorts, seasons	relationship between environmental conditions, disease and losses
Food use per unit output Growth performance	FCR (food conversion rate) SGR %/day (specific growth rate)	related to feeding efficiency and stock health. related to stock health, feeding rate, environmental conditions
Financial Indicators	Production cycles: net profit from different cohorts/ total for production period	related to mortalities, growth and FCR (feed ~40% total production costs).
SYSTEM INTERACTIONS		
Feedbacks between environment and production	all indicators above	observed impacts of fish farm induced environmental changes on the performance of fish stocks
Risks	losses, poor stock performance, impact on financial performance.	risk associated with underlying trends in environmental conditions and seasonal and annual variation in weather

5.3.2 Predicting and modelling impacts

This case requires some form of systems linkage to relate environmental interactions between fish farming and the aquatic system. This provides an exploratory structure for the system, as well as a practical means of assessing impacts of future developments. One aspect which is relatively well developed is the use of input-output and carrying capacity models to evaluate the effects of nutrient wastes from intensive farming operations. The approach is determined by the environment, marine or fresh water, flowing or static, and the type of development. The example presented below applies to temperate fresh waters, and is based on input-output models of phosphorus, as this nutrient generally limits productivity in these environments (Reynolds, 1984). The most commonly used models are those of Dillon and Rigler (1975) and Vollenweider (1975). The former has been adapted and applied to fish farm impact modelling by Beveridge and Muir (1982) and Beveridge (1984 and 1987).

The phosphorus loading produced by the potential fish farming operation is calculated as:

$$P_e = (P_f * FCR) - P_a$$

Where:
- P_e = environmental phosphorus loading (Kg/t fish produced)
- P_f = concentration of Phosphorus in feed (kg/t)
- P_a = concentration of phosphorus in harvested fish (Kg/t)
- FCR = feed conversion ratio (kg feed / kg fish)

The impact on the environment is:

$$[P] = L*(1-R)/ z*p$$

Where:
- [P] = predicted increase in total phosphorus (mg/m^3)
- L = areal loading of phosphorus from farm ($mg/m^2/yr$) (calculated from total annual loading / total water body surface area)
- R = sedimentation coefficient
- z = mean water depth (m)
- p = flushing rate (times / yr)

For a given site, with known mean depth, area and flushing rate, and a given "allowable" increase in phosphorus loading [P], the above equation can be use to calculate allowable L, from which the size of the farming operation can be determined. The application of this model to the Loch Fad system is discussed below.

5.4 Environmental impacts of the fish production system

5.4.1 System interactions and impact predictions

Although there were no data for the pre fish farm condition of the loch, the available evidence and the data recorded during the 1980s suggests that the fish farming operation has had a major impact on the level of eutrophication. This impact arises through the addition of nutrients to the system in the form of metabolic wastes, faeces and waste feed. Organic matter results in increased BOD (biological oxygen demand) cause by the microbial decomposition in the sediments and water column. The impact of dissolved nutrients is manifest through the phytoplankton bloom, in particular the level of dissolved phosphorus, which, as noted above, is generally the limiting factor in temperate fresh water environments. The interactions between key elements of this system, including the fish farm, the loch environment and external factors, are illustrated in Figure 5.3.

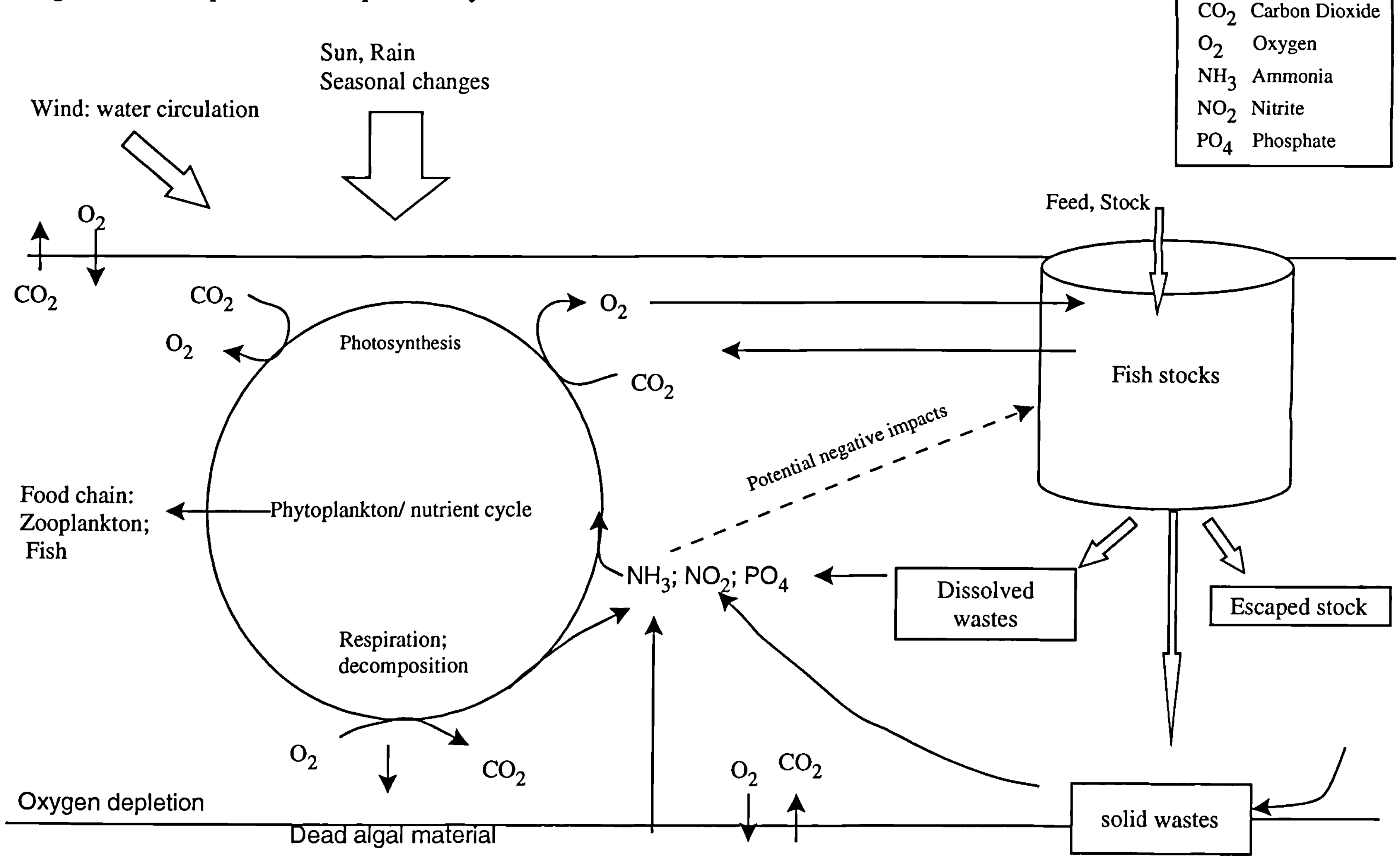
A key indicator of productivity of fresh water bodies is the level of phosphorus (P), which is reflected by the type, size and seasonal fluctuations of the algal population (Table 5.2). As fertility increases, there is an increasing dominance of blue-green algae at the expense of other phytoplankton (NRA, 1990). In hyper-eutrophic waters, blue green algal blooms dominate the phytoplankton for most of the year. By the early 1980s, this was the situation in Loch Fad (Dey 1984).

Table 5.2 Fresh water body classifications based on trophic state and total phosphorus (P) concentrations

Trophic State	P mg/m^3	Characteristics
Oligotrophic	< 10	-Nutrient-poor unproductive lochs, low chlorophyll and small proportion of blue green algae; unpolluted, multi use waters.
Mesotrophic	10 - 20	-Intermediate water quality characteristics, increasing blue green algae in later summer, increasing risk of blooms
Eutrophic	20 -50	-Highly productive, increasing domination by blue green algae during summer months, increasing frequency of blooms. Multi user nature of waters impaired.
Hyper-eutrophic	> 50	-As for eutrophic, increasing incidence and concentration of blooms, and potential for toxic blooms. Wide fluctuations in algal population; risk of total collapse and fish kills

(adapted from Phillips 1985 and Bostock 1987)

Figure 5.3 Fish production - aquatic ecosystem interactions



Before considering the outcome of the monitoring programme, it is useful to consider the application of the above input-output model to this system. Base on the classifications in Table 5.2, and the assumption that pre fish farm conditions were mesotrophic (Bostock 1987), with a total P of about 15mg/m^3, the model can be applied to estimate the total fish production allowable for specified changes in water quality criteria and trophic status. Table 5.3 demonstrates this for changes to lower, mid and upper eutrophic status (ie total P of 20, 35 and 50mg/m^3 respectively). Beveridge (1987) considers that water quality for the culture of salmonids should ideally be oligotrophic or mesotrophic, and suggests that while production in eutrophic conditions is possible, at the upper range (ie towards hyper-eutrophic) risk of adverse effects on production performance increase significantly. On the basis of this analysis, it is clear from the outset that this operation, with a production of about 200 tonnes in 1982 when this study started, was greatly exceeding the predicted limits for maintaining environmental conditions recommended for Salmonid culture.

Table 5.3 Modelling allowable fish production in loch Fad for specified water quality criteria.

Model formulae, inputs and assumptions

1 **Allowable production (t/ year) = TP/[Pt]**
where TP = Total phosphorous load, kg per year
[Pt] = kg P per tonne fish produced
= 17.7 kg at gross FCR of 1.5:1 (food input/ harvest plus mortalities)

2 **TP = L * total area of loch**
where L = areal [P]load mg/m^2/year; and Total area of loch = 71ha.

3 **L = [P]*z*p/(1-R)**
Where [P] =predicted increase in total phosphorus from baseline of 15 mg/m^3 tested here for increases of 5, 20 and 35 mg/m^3
z = mean depth of loch = 5m
p = flushing rate of loch = 2 (per year)
R = 0.8 (Beveridge 1987)

Outputs tested for three levels of allowable P impact

Loch condition	meso/eutrophic	eutrophic	eutrophic/hyper-eutrophic
Allowable P			
-Total mg/m^3	20	35	50
-Increase mg/m^3	5	20	35
Allowable production	10 t/year (ideal)	30t/year (acceptable, risk)	70t/year (high risk)

5.4.2 The annual cycle and short term changes

The annual changes in the production environment follow the patterns typical of small, well mixed and highly eutrophic temperate water bodies (see Annex 1, Figures 1-8, for details of years 1982-1984). The seasonal dynamics of the algal bloom, measured by chlorophyll 'a' (Annex 1, Figure 2) is the main internal factor which influences changes in other water quality parameters. The size, health and distribution of this bloom are influenced by changes in the seasons and, in the short term, weather conditions. These seasonal and short term fluctuations have a major impact on dissolved oxygen (DO) levels, turbidity and breakdown products from decomposing algae (ammonia and nitrite), which in turn can result in significant negative impacts on the viability of the fish farming process itself. These impacts are discussed below.

5.4.3 Long term trends

A summary of averages and extremes in water quality, feed inputs and fish outputs over the period of study are presented in Table 5.2 . All water quality data, with the exception of winter dissolved phosphorus (DP) levels, relate to the summer months, when extremes in conditions relevant to the performance of the fish farming operation occur. Winter levels of DP reflect the total available phosphorus in the system, indicating trophic status. During the summer months, a significant proportion of this is incorporated into algal biomass, reflected in the lower levels recorded.

The interpretation of trends in water quality data is complicated by a number of factors. Firstly, as the weather influences the development of algal blooms and other water quality parameters, annual variations and longer term trends must be seen in the context of prevailing weather conditions. Variations in management practice of the fish farming operation (level of feed used, and the efficiency of the feeding process) also influence the impact on the aquatic environment in terms of the level of dissolved and solid wastes entering the system from year to year. A further complexity arises in terms of the impact generated by these wastes: a proportion being manifest immediately and in the short term (fish respiration and metabolic wastes, and biological oxygen demand (BOD) and nutrients released from breakdown in the short term), while longer term impacts occur through slow breakdown and nutrient release from sediments (Phillips, 1985).

Table 5.4 Water quality in Loch Fad: summary data 1982-1986

	1982		1983		1984		1985		1986
Temperature C									
May	12.3		11.6		14		11.4		10.5
June	16.3		15.1		16.4		15.8		15.2
July	18.3		19		18.2		16.2		16.2
August	16.9		19		19		14.8		15.6
Average	16.2		16.2		16.1		14.6		14.3
Dissolved oxygen mg/l									
Loch Average June-Sept	9		8.3		7.7		7.4		7.5
Cage average June	6.8		7.9		5.5		7.6		8.4
July	7.7		5.9		7		5.9		6.2
August	7.3		6.8		6.3		5.4		5.2
September	8.5		6.3		4.6		5.7		4.9
October	7		8		6.9		5.3		5.7
Cage average June-Sept	7.5	(1.1)*	6.4	(0.5)*	5.9	(0.2)*	6.1	(0)*	6.1
Minimum 24 hr cage level	5.8	(1.6)	4.2	(0.5)	3.7	(0.2)	3.5	(0.6)	2.9
Chlorophyll'a' (µg/l surface)									
June-September	62		108		76		48		47
Secchi disc (m) average	0.93		0.77		0.57		0.98		1.1
weeks below 0.5m	0		10		10		0		0
Nutrient levels (µg/l) (June-Sept)									
Ammonia average	216		300		430		493		1007
peak	400		700		800		1000		1857
Nitrite average	12		35		44		44		86
peak	140		310		150		66		168
Phosphate average	29		35		39		80		94
(peak winter levels)	(100)		(140)		(140)		(220)		(400)
Food input (tonnes dry weight)									
01 April-31 August	108		172		346		180		203
01 January-31 December	254		374		508		315		395
Fish harvests (tonnes)	213		210		260		258		300

*( ) = decrease/increase in oxygen level from one year to the next

The potential improvement in conditions arising from any reduction in the level of inputs will therefore be masked by the effects of waste accumulation from previous years. The rate of water exchange (in this case an average of twice per year) will also influence the rate at which dissolved nutrients are flushed from the system.

While these factors limit the development of deterministic relationships between these data, a number of broad observation can be made. The main long term features appear to be that average levels of recorded nutrients rose over the five years (Stewart, 1987), in spite of the fact that the peak food input was in 1984, with lower usage in the following two years[1]. The average dissolved oxygen (DO) levels also decreased over the period, but less so in later years. The fluctuation in the average levels of chlorophyll 'a' (chl 'a') and the secchi disc reading (turbidity) do not show any particular pattern, as the levels of the algal bloom which develops is largely dominated by the weather conditions. The cooler temperatures in 1985 and '86 indicate less stable weather than in previous years, associated with greater mixing, which inhibits the development of blue-green algal blooms (NRA, 1990). The fact that dissolved phosphate could be detected throughout the summer (except on occasions in 1982, illustrated in Annex 1, Figure 8) suggests that the development of the bloom was light, rather than nutrient, limited.

From the fish farmer's perspective, the most important element is the oxygen level. The average DO levels in the loch show a steady but diminishing rate of decrease from 1982 to 1985, with little change in 1986. Levels recorded inside fish cages showed a steady decline in the minimum 24 hour average recorded over the summer months (see also Annex 1, Figure 4c). Given that temperatures, weather conditions and the reduction in food inputs could be expected to have resulted in an increase in the DO levels in 1985 and 1986, in comparison to the previous two years, the results suggest an underlying deterioration in the loch environment had occurred.

The implications of both long and short term environmental change for the commercial viability and sustainability of the farming operation is discussed below.

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[1] feed input in one year relates to a proportion of output in the following year. From 1984, in addition to increasing output of portion sized fish, a proportion of stock was held for ongrowing to 1.5-2kg, for harvest in the following year.

5.5 Feedback from the environment to fish production

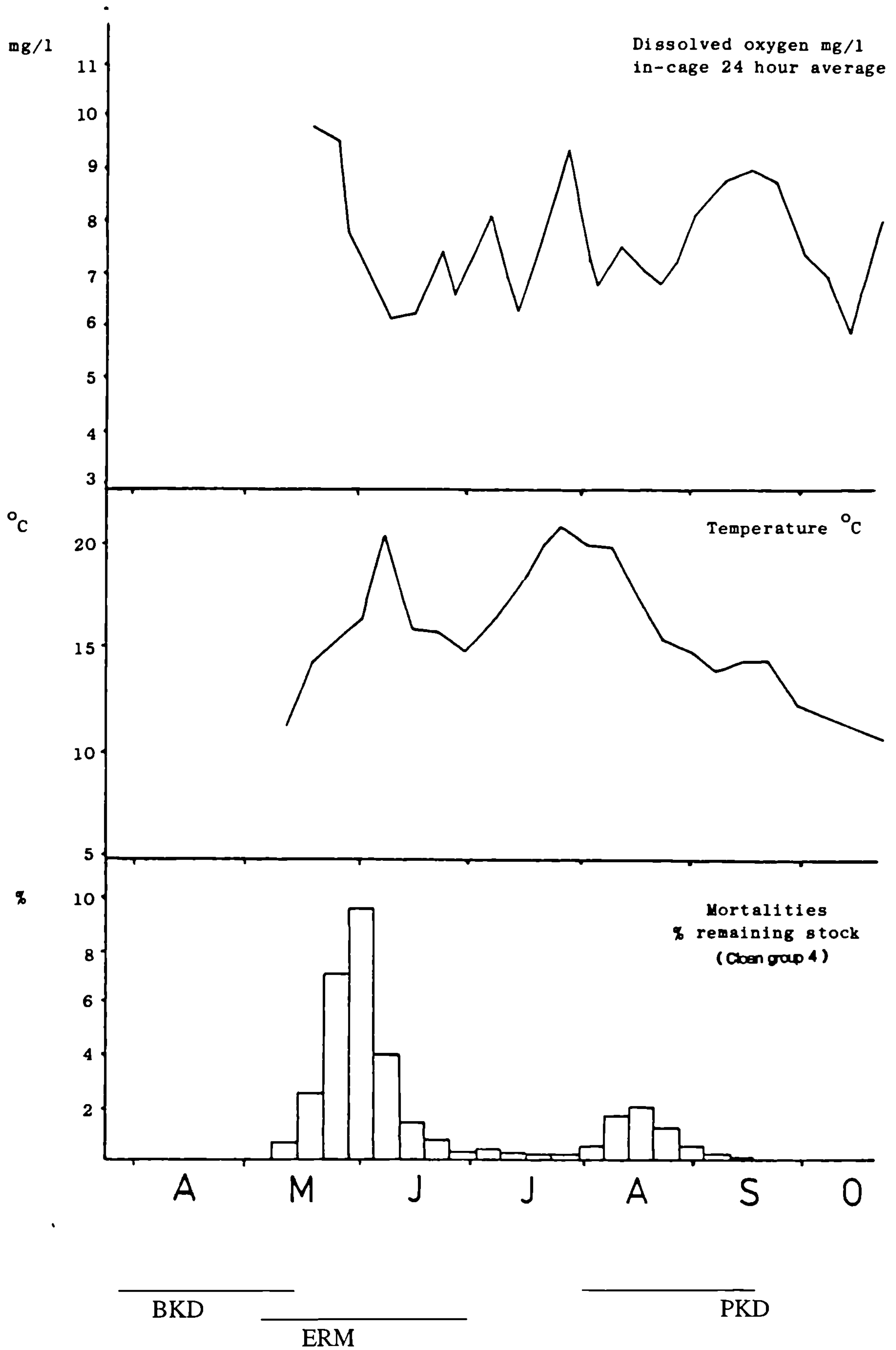
5.5.1 Annual trends and risks

The focus of the environmental monitoring from the perspective of the farm management was to ascertain the link between environmental changes, production performance and ultimately profitability. The health of fish stocks was therefore a critical element of the programme, both in terms of health status, which influenced feeding and growth, and mortalities.

The monitoring of the disease in fish stocks showed clear seasonal trends in the presence of major fish pathogens. The incidence of stock loss, however, depended on the combined effects of the environmental conditions and underlying health of stocks. While high temperature and low oxygen levels did appear to stress fish stocks and reduce growth performance, these conditions alone did not necessarily cause high stock losses. However, such conditions occurring at a time of major disease outbreak could result in very high losses, due to the anaemic condition of diseased fish, combined with low DO levels and increased metabolic demand. Due to the interaction between the presence of disease and the water quality conditions, the level of losses associated with each disease condition, and the overall annual losses, varied from year to year.

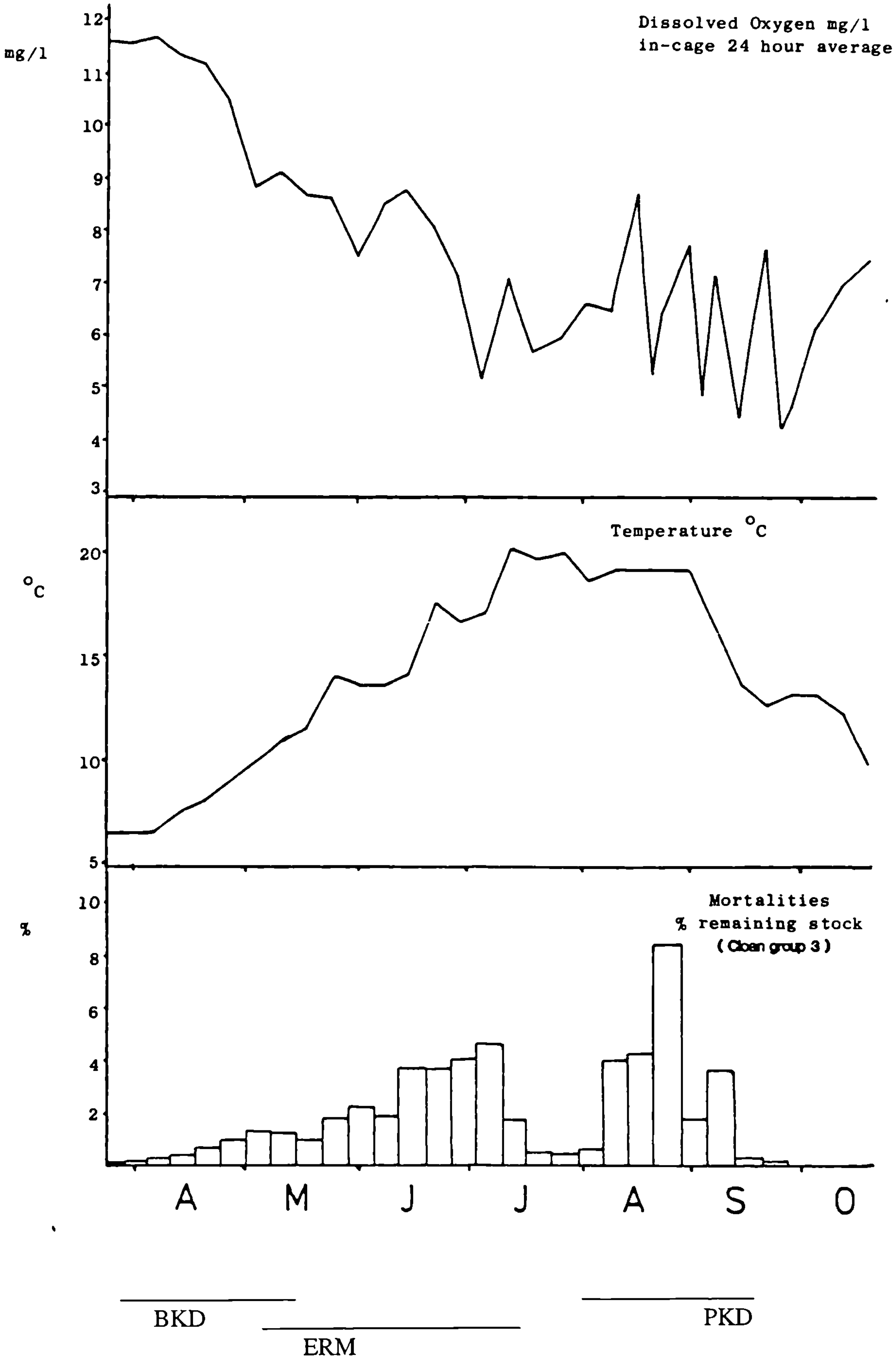
For example, Figure 5.4 and 5.5 illustrate the pattern of losses in stocks produced over the summer months. In 1982 (Figure 5.4), high losses occurred in late May and early June, associated with a very rapid rise in temperature and sharp decline in DO levels, at a time when two disease conditions (BKD and ERM) were diagnosed. Losses associated with the third major disease condition (PKD) in August, although significant, were relatively low. In 1983 (Figure 5.5), a more gradual change in temperature and oxygen conditions over the spring and early summer was associated with a more gradual build-up in losses. However, these were more sustained through June and early July, and very much higher in August, during the outbreak of PKD. The higher losses in the late summer of 1983 were associated with periods of considerably lower oxygen levels and higher temperatures than in 1982.

Figure 5.4 Seasonal changes in water quality and mortalities, 1982



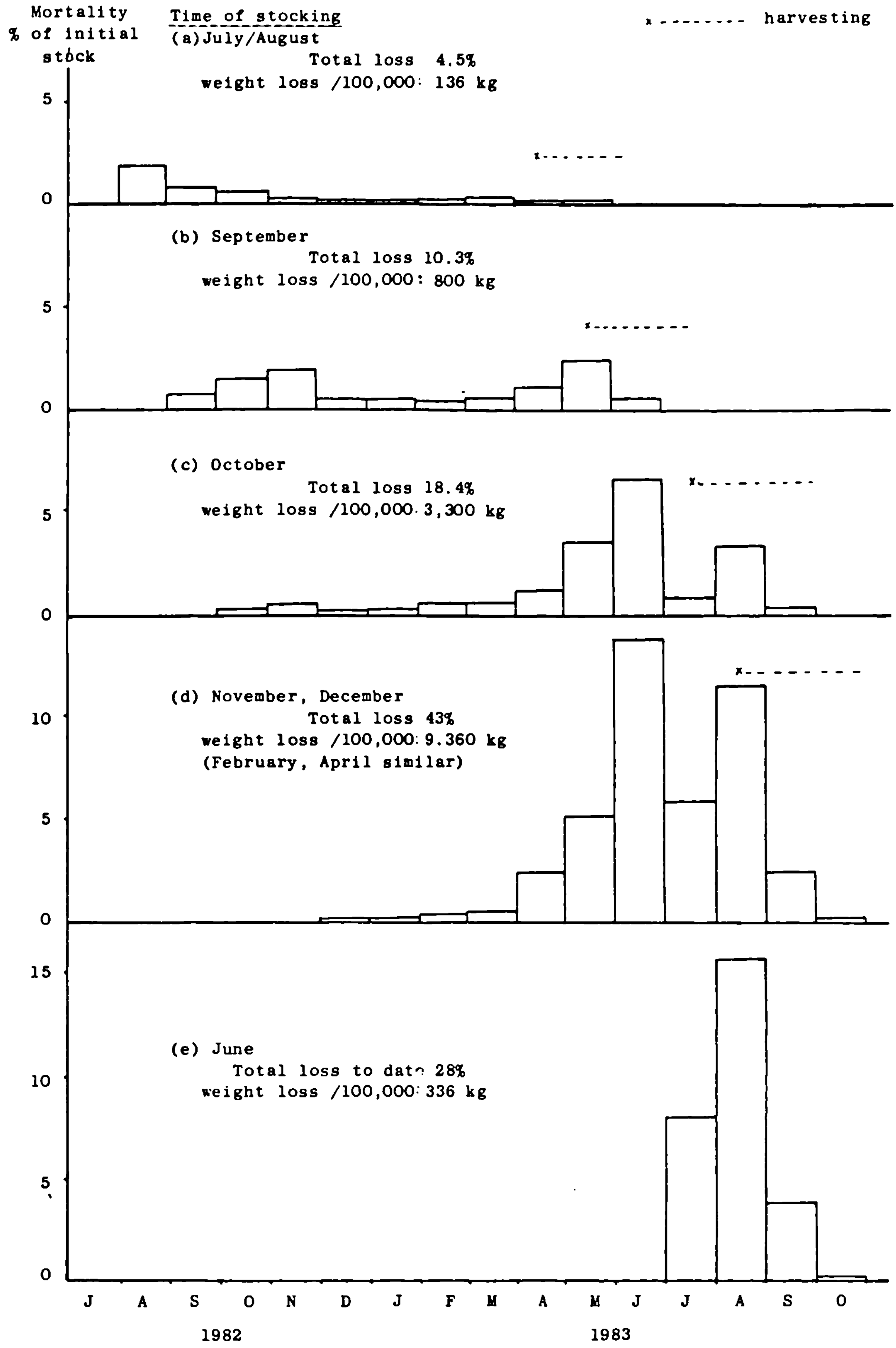
BKD (Bacterial Kidney Disease); ERM (Enteric Redmouth Disease); PKD (Proliferative Kidney Disease)

Figure 5.5 Seasonal changes in water quality and mortalities, 1983



BKD (Bacterial Kidney Disease); ERM (Enteric Redmouth Disease); PKD (Proliferative Kidney Disease)

Figure 5.6 Mortalities in relation to time of stocking 1982/1983



In addition to the combined effects of disease and water quality fluctuations, the level of losses sustained by different stocks during high risk periods varied with the time of stocking, and other management variables. The latter included stocking density in fish cages, and activities causing stress during high risk periods, such as grading or moving stock, and also feeding, which increases metabolic oxygen demand.

The observed variation in losses sustained by fish stocked at different times of year is illustrated in Figure 5.6. These variations were in part due to the fact that not all stocks were held over the high risk periods, and also that larger fish were less susceptible to early summer disease conditions, although increased losses did occur. Fish stocked in July and August, although in the loch during the PKD outbreak, did not have time to develop such acute symptoms (normally about 8 weeks from first exposure) before temperatures fell in September, allowing recovery (Clifton-Hadley *et al*, 1987). Stocking in June 1983, however, did result in very high losses, primarily associated with PKD in August and September. While the actual level of losses for different stocking periods will vary from year to year, there are clear signs of periods of greater and lesser risk. The implications of these trends are discussed below.

5.5.2 Short term fluctuations and risks

The above results are focused on weekly monitoring which illustrates the broad trends in environmental conditions and stock losses through the year. However, it was clear that during the summer months, conditions could change very dramatically, sometimes in a matter of hours, associated with changes in the health and distribution of the algal bloom. While the oxygen demand cause by a collapse in the algal bloom was most marked at the end of the summer, fluctuations in DO levels were associated with changes in the size of the algal bloom throughout the summer.

The potential impact of a sudden collapse in the algal bloom, in terms of the theoretical oxygen demand of a given decrease in the living algal levels (measured by chlorophyll 'a'), was found to match reasonably well with the actual decrease in DO recorded after such a change (Table 5.5) Clearly, some indication of the potential for low oxygen levels could be drawn from measurements of the algal levels.

Table 5.5 Predicting potential oxygen depletion following a collapse in the algal bloom.

a) Calculation of potential oxygen demand from Chlorophyll 'a' levels.

Assume Chl 'a' levels before collapse in bloom	120µg/l
after collapse in bloom	20µg/l
Change in Chl 'a'	100µg/l
Equivalent to total organic matter load (derived from relationship between Chl'a' and suspended solids through the year)	14mg/l
Biological Oxygen Demand @ 0.52 mg O_2/mg organic matter (Phillips 1985)	7.3mg/l
Assume Oxygen levels prior to collapse	9.0mg/l
Then potential Oxygen level after collapse	1.7mg/l

b) Comparison between estimated and recorded oxygen depletion

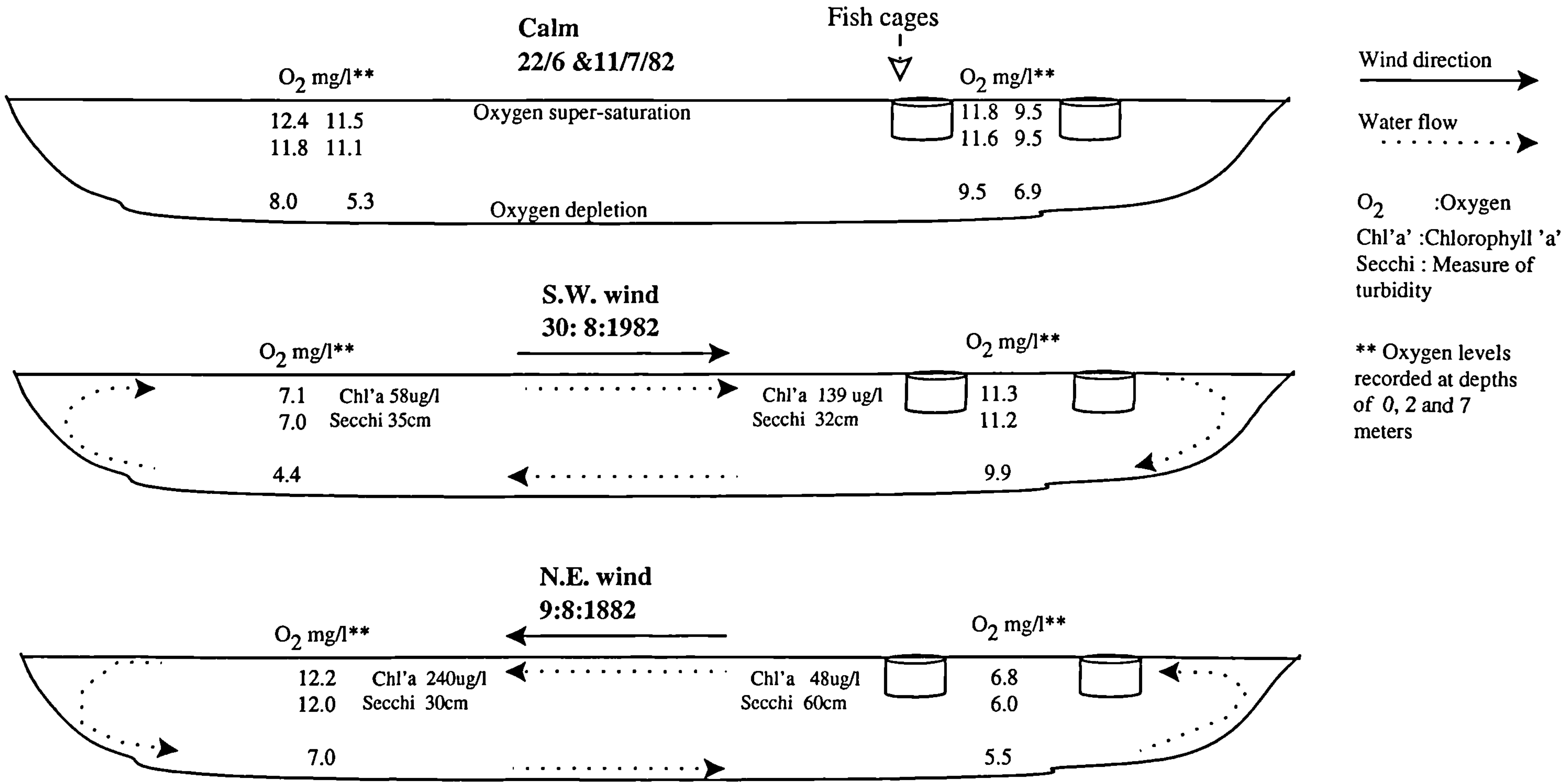
Date	Decrease in recorded Chl'a' µg/l	Estimated organic load (mg)	Estimated O_2 demand (mg/l)	Recorded fall in O_2 levels (mg/l)
19/4 - 3/5/83	30	4.2	2.2	3.3
7/6 - 5/7/83	75	10.7	5.5	4.5

Note: calculation represents illustration of the potential for oxygen depletion. Discrepancy between estimated and recorded change will be influenced by: sedimentation of organic matter; rate of breakdown; oxygen inputs from atmosphere (influenced by weather conditions).

In addition to total algal biomass, the distribution of this bloom within the loch was also observed to have a major effect on environmental conditions around the fish cages, and therefore to influence the risk of losses. During periods of hot stable weather, high oxygen levels in surface waters were associated with large build-ups of phytoplankton[1], and supersaturation of oxygen levels, while in the deeper waters lower oxygen levels were attributed to the oxygen demand created by respiring and decomposing algal cells, in addition to the BOD of sediments (Figure 5.7). At such times, despite high surface temperatures, losses were generally low. However, if such stable conditions were followed by light NE winds along the length of the loch, the resulting surface water movement caused upwelling of oxygen-poor waters around the fish cages, indicated by a colour change from rich green to muddy brown, the latter being due to the abundance of dead algal cells. When this occurred during periods of disease, very dramatic increases in stock loss occurred.

[1] conditions which favour the development of blue-green algal blooms (NRA 1990)

Figure 5.7 The influence of wind on water quality at the cage site (loch profile)



This phenomenon was most common during summers with long periods of hot stable weather, which correlated with low rainfall data. These years also resulted in the highest stock losses. Summers with unstable weather, associated with lower temperature, greater wind induced mixing and higher rainfall, generally had lower losses. On this basis, one possible indicator of the likely frequency of favourable and unfavourable weather conditions for fish farming was the past rainfall data. This suggested that over the previous 20 years, one year in five would produce conditions which might result in very high stock losses, assuming no change in the scale of the fish farming operation or underlying environmental conditions (Stewart, 1983).

5.6 Management implications of environmental changes

The objective of the monitoring programme was to assess the implications of the observed relationships between fish health, water quality and weather conditions for both the short and the long term management of the production operation.

5.6.1 Short term changes

In the short run, it was clear that although the annual losses depended very much on the weather conditions over the summer months, there was significant variation in losses sustained by different stocks. The commercial viability of the different cohorts is illustrated in Table 5.6 and Figure 5.8, which presents an estimate of the % return on costs for a range of food conversion ratios. The variable FCR is applied to the analysis to illustrate the impact of this indicator on the commercial performance, but also because at the time no records were kept for feed inputs to each stock group (recording began in 1985). Based on FCRs recorded for specific groups, and estimated for the whole farm over the year (total input / output data), the FCR in 1982/83 stocks was about 1.6:1. Estimates of farm gate returns at this FCR suggests a small loss was made on these stocks (Table 5.6). Comparison of different cohorts (Figure 5.8) suggests that those stocked between October and April made a loss, June stocks just covered costs, while July to September stocks returned a profit. A similar pattern occurred in later years, although the actual level of profit/loss varied depending on the summer weather conditions and level of losses. An example for 1985-86 cohort performance is presented in Figure 5.9, when the FCR was estimated at about 1.4.

Table 5.6 Cost Analysis for stocks received from July 1982-June 1983

a) Costs and returns for different cohorts

(Costs, Profit and Returns estimated for FCR 1.5 (top figures) and 1.8 (bottom figures)

Stocking time	No. fry x 1000	Mortalities x 1000	Mortalities %	Mortalities kg	Mortalities kg / 10^5	Sales (tonnes)	Costs £	Revenues £	Profit/Loss £	% return
July/Aug	350	15.75	4.5	476	136	83.56	74958	87323	12365	16.5
							85043		2280	2.7
September	240	24.72	10.3	1920	800	53.82	50268	56242	5974	11.9
				0			56957		-715	-1.3
October	240	44.16	18.4	7920	3300	48.96	50952	51163	211	0.4
				0			57778		-6614	-11.4
Nov/Dec	200	86	43	9360	4680	28.50	36736	29783	-6954	-18.9
				0			41279		-11497	-27.9
February	90	36	40	3644	4049	13.50	16595	14108	-2488	-15.0
							18653		-4545	-24.4
April	60	25.2	42	1870	3117	8.70	10548	9092	-1457	-13.8
							11817		-2725	-23.1
June	100	28	29	336	336	17.75	17862	18549	687	3.8
							20032		-1483	-7.4

b) Summary for all stocks, demonstrating significance of changing FCR

FCR (see note 6)	No. fry x 1000	Mortalities x 1000	Mortalities %	Mortalities tonnes	Sales (tonnes)	Costs £	Revenues £	Profit/Loss £	% return
Totals	1280	260	20.3	25526	254.8				
@ 1.5						257919	266258	8339	3.2
@ 1.8						291558		-25299	-8.7
@ 1.6						**269132**		**-2874**	**-1.1**

Assumptions
1. No allowance for unrecorded losses (particularly high in summer stocks)
2. Total weight loss per cohort based on sum of average weight for each month of production x number of losses per month
3. Fish sold to factory @ 250g for £1,045/tonne (47.5p/lb).No fish held for ongrowing.
4. Losses costed as food equivalent at specified FCR
5. Overheads, labour and capital costs similar for all groups, calculated on a unit volume/time rate (i.e. per cage month)
6. Feed and fry costs constant @ £400/tonne and £30/1000 respectively
7. Estimated FCR for financial year 1982/83 was 1.6:1.

Figure 5.8 Estimated returns 1982/83
Vary time stocked & FCR

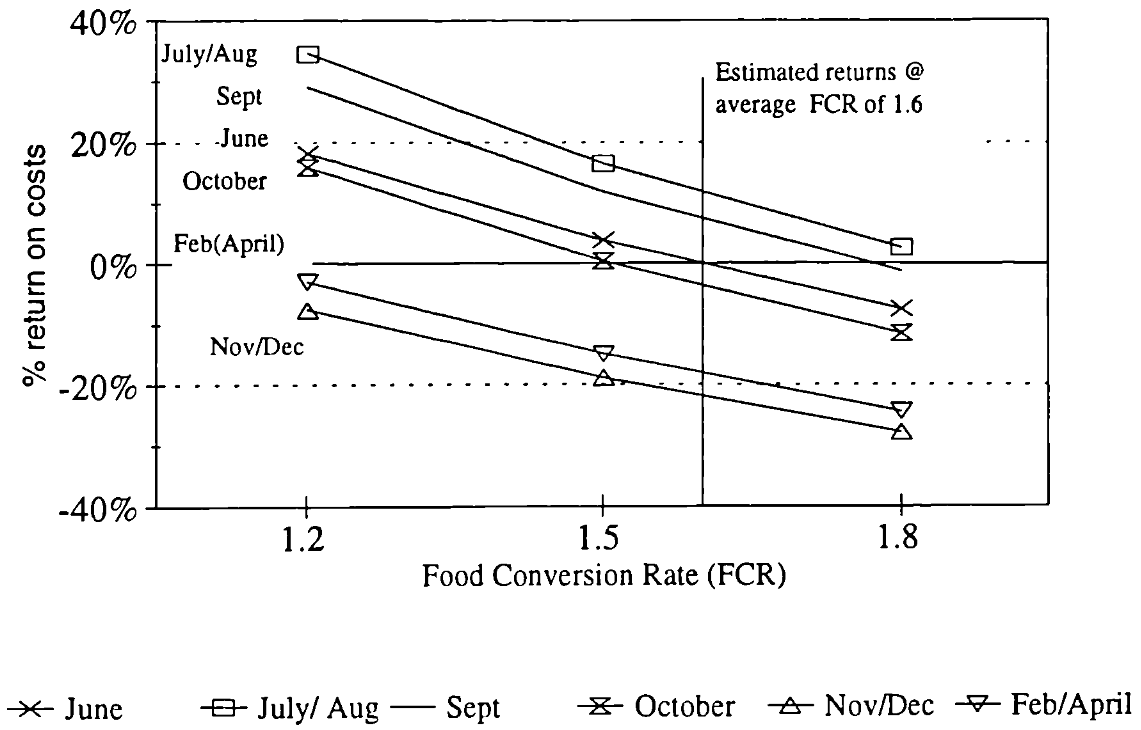
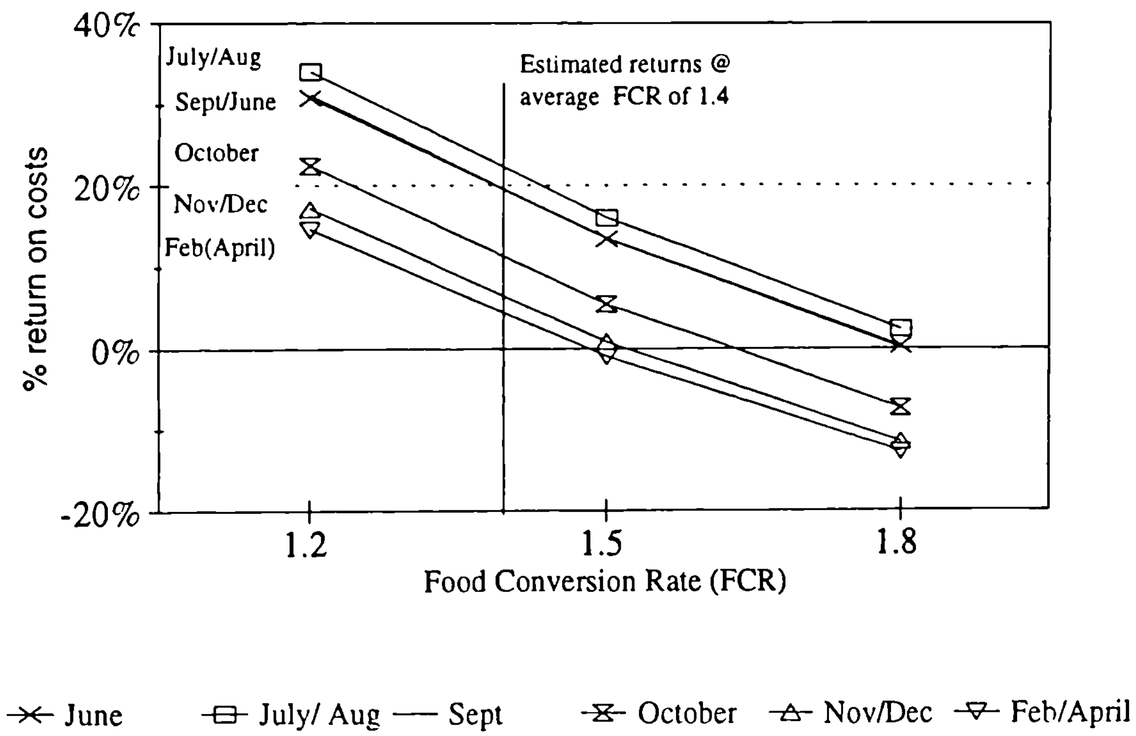


Figure 5.9 Estimated returns 1985/86
Vary time stocked & FCR



In addition to the external impact of weather and water quality on stock performance, significant changes in management are believed to have contributed to the reduction in total summer losses and improvements performance. Management changes include the reduction of stocking density (by increasing the number and volume of cages), improving the quality of purchased stock (BKD free stock reduced losses in April and May), treatment of disease outbreaks where appropriate (ERM), improved husbandry during periods of high risk, and better control of feeding resulting in an improved FCR.

5.6.2 Long term viability of the operation

The long run viability of the commercial operation clearly depended on the ability to generate sufficient surpluses in good years to withstand periods of loss during particularly bad years. Due to the large number of variables which influenced the performance and returns in any one year, definitive predictive statements on future viability, or sustainability, of the farm were not possible. However, environmental monitoring suggested that there had been a general deterioration in water quality over the 5 years of study, particularly in terms of falling oxygen and increasing nutrient levels, although changes from year to year were masked by changes in weather conditions. While improved stock management and favourable weather are believed to have contributed to the better production performance in 1985 and '86 than over the previous two years, the underlying deterioration gave some cause to question the sustainability of the operation.

To consider the predictability of the long term trends, it is useful to review the comments made at the end of the monitoring programme, and compare these with the actual outcome. The final report to the company (Stewart, 1987) concluded that:

> "the implication of these trends for the future...... are likely to be serious unless some action is taken to at least stabilise the underlying deterioration in water quality conditions".

> "Contrary to earlier intentions to reduce production, more recent targets of 250 to 300 tonnes have been considered. This gives considerable cause for concern, as this is likely to result in a continued deterioration in conditions. It is not possible

to quantify the rate or magnitude of this change due to the variability in annual weather conditions. Given improved stock management, the operation may continue with tolerable losses for a number of years. However, in view of the very low oxygen levels already recorded ... any further decreases will increase risk of catastrophic losses under certain conditions".

"In view of this, it is strongly recommended that the production policies be reconsidered, and attempts made to reduce the total output while maintaining a commercially viable unit. The benefits of current policy are likely to be short lived, and in the long term may have very serious consequences for the whole operation".

The advisory contract ended in early 1987. A new manager, with a biological background, was employed to take over management of both the fresh water site, and the expanding marine site. Production in the fresh water site was maintained at 250 -300 tonnes per annum for the following 5 years, during which time the farm apparently experienced increasingly serious losses during the summer months.

The holding company underwriting the investment pulled out in late 1992. The sea water operation and processing unit were closed down, while the staff and new management bought out the fresh water facilities. The decision to continue production in the fresh water loch was based on the belief that the operation could be viable at a lower level of production (target of about 80 -100 tonnes per annum) (Stewart, 1992). This new company was still in operation in late 1994.

5.7 Sustainability perspectives

5.7.1 Commercial and environmental sustainability

In crude commercial terms this operation might have been judged to be unsustainable, and that environmental impacts, driving the ecosystem from mesotrophic to hyper-eutrophic had reduced average performance and increased risks to unacceptable levels. However, the reasons for the business continuing to operate at an output level which seriously threatened the viability of the farm, against the recommendations arising from the monitoring (for which they paid), were clearly more complex.

This must first be seen in the historic context of the firm, which evolved from a family run seafood processing operation established in the early 1970s with backing from a holding company with local interest and support from the HIDB[1]. The activities of the holding company financing this operation (and a range of other activities both on and off the island) were strongly influenced by the issue of local employment: by the early 1980s this firm was the largest employer on the island. With decreasing local availability of prawns and scallops in the late 1970s and into the 1980s, the continued operation of the processing factory became more dependent on trout. The volume of factory through-put required to stay in business was the principal reason that the management initially increased trout production, and later were reluctant to reduce output in the short term. The investment in the marine production site, starting in late 1984, did indicate that they were aware of the problems and the limitations of the fresh water site in terms of meeting the company's long term objectives. However, this did not bring any significant changes in production levels for the rest of the decade.

It is not clear to what extent decisions were made in ignorance of, or simply ignoring the risks involved at the time: there was a tendency for management to take an optimistic view, and see external advice as useful in developing short term management practice dealing with environmental change, but as over cautious in strategic terms, a view which ultimately contribute to the failure of the business. However, the continued production from this site by a small independent company, with considerably reduced outputs,

[1] Highlands and Islands Development Board

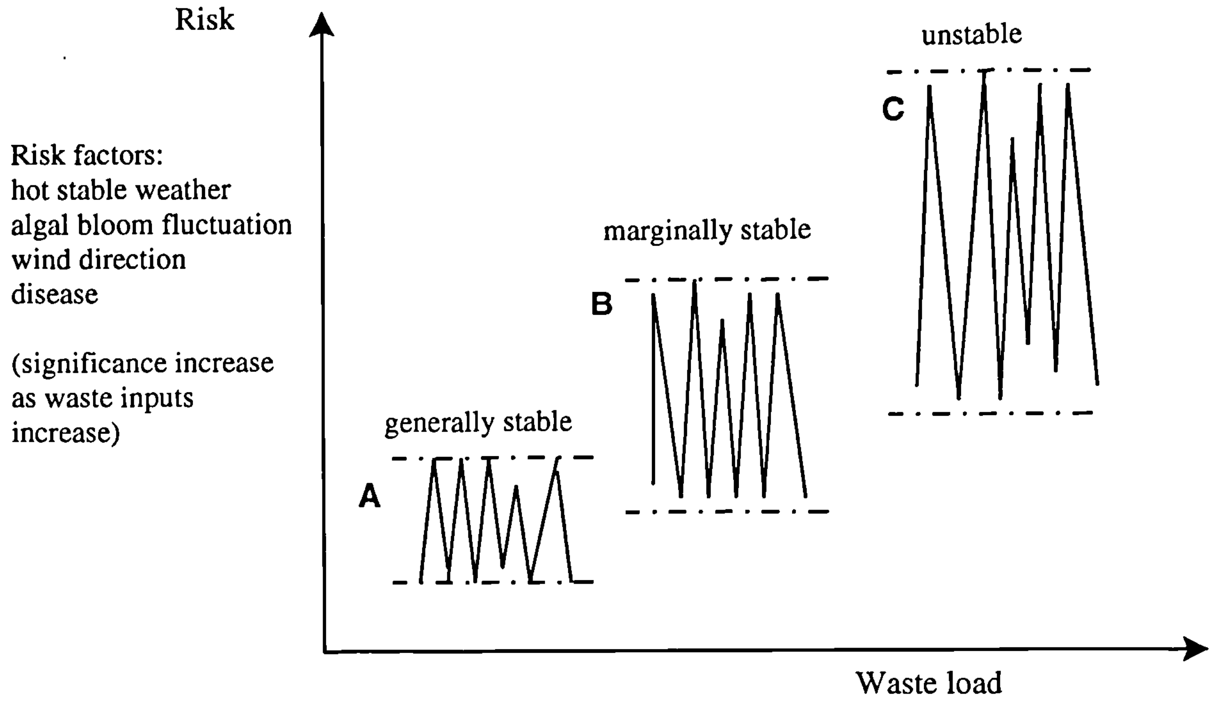
indicates that the previous environmental impacts were not so severe that fish farming could not be sustained... only the scale and organisation of that activity had to be changed. Without considering any wider impacts, it could be argued that the initial fish farming operation, although not commercially sustained in the long term, was not ecologically unsustainable at the local system level.

The behaviour of the management process in this case raises important question concerning the use of scientific information, and the approach to risk, both at the level of the firm, and society in general. The potential sustainability implications of development policies based on either optimistic or pessimistic views, in the event of either of these views being right, have been illustrate in simple terms as a payoff matrix, presented in Chapter 2 (Table 2.1) in the context of global sustainability. Applying this to the above case, it could be concluded that the optimistic policy of the firm, going against the more conservative recommendations derived from the impact models, which in the event appeared to be right, lead to the 'disaster' predicted by this simple conceptual model.

While this interpretation appears to fit, this is clearly over simplistic. Over the period of study, about 1850 tonnes of food (dry weight) entered the system, and about 1240 tonnes of fish were produce (dry weight of 370 tonnes), in contrast to the recommended sustainable production level which would have produced 150 tonnes of fish (at an allowable level of 30 tonnes per year, calculated in Table 5.3). What is significant is that this level of discrepancy between advised and actual production levels (by a factor of 8) continued for almost a decade. Furthermore, the continued operation of the new company, producing about 80-100 tonnes per year, is still above the level of output which the model suggests represents a high risk.

Figure 5.10 illustrates a more dynamic interpretation of the relationship between levels of production and commercial risk. The generally stable level production represented by area A, could be taken to represent an output of 10 tonnes per year, forecasted by the input-output model in Table 5.3 to increase the trophic status of the loch to the lower end of the eutrophic range (Table 5.2). The model also predicted that an annual outputs of 30 and 70 tonnes represented moderate and high risk options, which could represent points B or C, respectively: the implication being that the actual output of about 250 tonnes would not be sustainable.

Figure 5.10 Waste inputs and commercial risk



Areas A,B and C illustrate the potential for variability in commercial performance, and degree of risk, associated with normal variations in weather conditions and increasing levels of wastes entering the system.

While this proved to be the case in the long run, the model overlooked the potential for management adaptations to short term risk which actually improved performance, in spite of deterioration environmental conditions over the period of study. It also appears that the continued production of the new company, at about 100 tonnes per year, represents a stable -marginally stable operation.

This suggests that the model produced a conservative estimate of the allowable production in terms of the sustaining a commercially viable operation. One of the principal problems in the use of impact models is that the while they can provide general guidelines on level of outputs acceptable for given water quality standards, there is likely to be a large margin of error, in this case on the conservative side: while the pursuit of economic activities which operate within the safe boundaries predicted by such models might represent an ideal goal for more sustainable development, there is a need to consider the trade-offs this involves in term of the economic viability of the development, and the level of economic and social benefits which can be derived from a given resource base.

5.7.2 The issue of wider impacts and sustainability

The analysis so far has taken a restricted focus, setting the boundaries of the fresh water loch as the ecosystem component, and the business entity as the commercial component. There is clearly a much wider set of issues. There is the question of impacts on the utility of other users of the loch or surrounding environment: how does the activity, and the change in water quality influence values derived by others? The linkages of the loch with the enveloping ecosystems, in particular the impacts of nutrient outflows to the coastal environment, must also be considered: do the more 'external' factors outweigh those identified within the narrower boundaries?

The significance of the environmental impacts for other users is highly site specific, and related to past, present and potential future uses. Prior to the fish farming activities, the two principal uses were sport fishing and livestock water supply, neither of which appear to have been compromised by the fish farm development. The pre-fish farming fishery was dominated by coarse fish (pike,perch and roach) and brown trout, while following the introduction of the fish farm, rainbow trout represented an increasing proportion of the catch, the population of which was largely supported by the escapees form the fish cages. Anglers also reported that the maximum size of both perch and roach has increase considerably, attributed to the increasing productivity of the loch. The population of both pike and brown trout was reported to have decreased. The pike were heavily netted in the late 1970s to reduce predation on rainbow trout. It is also believed that the presence of large numbers of rainbow trout has caused a reduction in the success of recruitment and survival of brown trout from the two streams feeding the loch (Phillips et al, 1985a). The overall impression from anglers, the main recreational users of the loch, is that the fish farming operation has improved the resource: this is now a nationally recognised sport fishery (recently the focus of a national television programme), and has attracted increasing numbers of anglers to the island, which can be assumed to have brought some economic benefits to the island economy.

The other principal use of the loch is as a source of drinking water for livestock. This does not appear to have been adversely influenced by the eutrophication. However, there is evidence that livestock and people can suffer from the ingestion or contact with toxins from algal blooms from such hyper-eutrophic water bodies (NRA, 1990; Falconer, 1993), and such toxic blooms have been recorded in this loch (Phillips et al, 1985b). It is therefore possible that such problems could occur.

The significance of the additional nutrient enrichment of the coastal environment caused by the fish farming operation is uncertain. Set in the context of the other sources of nutrients, including urban, agricultural and forestry sources, it is likely that this source is insignificant, although this was not investigated. The need to set the evaluation of specific activities within a wider development context has been recognised above as an essential feature of pursuit of sustainability. Thus there is a need not only to assess the impacts of specific activities, but also to identify valuation mechanisms by which impacts can be equated with defined levels of benefits for alternative resource use options. Examples comparing economic value per unit nutrient impacts for aquaculture and other industries have been presented by Muir (1993), and FAO (1993b). The issue of internalising environmental impacts in economic evaluation is discussed later.

5.7.3 The role of indicators

The choice of indicators of environmental condition and production performance in this case was based on the perceived importance of particular factors in relation to commercial sustainability. It is clear that certain indicators can be used to inform on the likely state of other aspects of the system. The level of fish production and food conversion efficiency gives an indication of the level of wastes, and likely eutrophication in a given environment. Hyper-eutrophic conditions suggest the likelihood of poor environmental conditions for fish culture of this type, and increasing risks of high stock losses; high losses suggest that the financial performance will be poor.

Although it is possible to surmise general relationships, the above study shows that within broadly defined operational boundaries, it is the combination of many elements in a highly complex system which determine the outcome from given events. Simplistic, individual indicators were not sufficient in themselves to provide a view on the sustainability relationships. Further, *a priori* understanding of the ecological processes based on conventional fresh water ecology was not sufficient, particularly in characterising the relationships between risks and returns. It was only through regular monitoring over a number of years that interrelationships could be inferred, and conditions relating to poor performance highlighted. Periods of higher risk within the annual cycle could be identified, but definitive predictions were not possible within the bounds of the level of data collection which this operation could support: in systems terms the relationships were too open to allow deterministic relationships to be derived[1]. As with any system which is weather dependent, the short run predictability is generally poor, although longer term performance, based on past trends, can, to a certain extent, be more reliably forecasted.

The fact that this commercial operation was not "sustained", and that the management apparently chose to ignore the long term risks which the available measures indicated, is believed to be due to both the short term cash flow needs of the whole business operation, and the tendency towards optimism in the face of uncertainty: things were all right this year, so let us continue. The problem here, although perhaps an extreme case, reflects the problems generated by the imprecise nature of the whole concept of sustainability, and the lack of any definitive indicators by which this can be assessed. These include the tendency to disregard uncertainty with an optimistic, or status quo view, and the issue of "social traps", the conflict between short term needs (perceived or real) and the long term "good". These issue will be discussed more fully in later chapters.

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[1] given the complexity and openness of the system, while data collected provided an indication of interrelationships between different factors, the statistical strength of this information is poor. It is also likely that even with considerably more detailed and costly data on the system, development of deterministic relationships and accurate predictive models would not be possible.

5.7.4 The role of models and classification

The application of the input output model above provided general guidelines, rather than offering definitive predictive capabilities. Such models are clearly simplifications of reality. The above model assumes that impacts are evenly dispersed (perhaps not so if site is near the outflow of a loch), and that indeed phosphorus is the limiting factor in the system[1]. The interpretation of results must therefore be set clearly in the context of the assumptions, and the characteristics of the site in question.

In the above case the physical characteristics of the site are believed to have contributed to the tolerance of higher levels of waste loading than recommended by the model: being shallow, and lying alone the line of the line of the prevailing winds, is believed to have been the major factor preventing long term stratification during the summer months, which in turn prevented the buildup of anoxic layers which could potentially catastrophic consequences for the fish farming operation (only moderate effects of this sort occurred, illustrated earlier in Figure 5.7). The initial trophic characteristics of the system are also likely to have been a significant factor in the ability of the system to assimilate higher levels of waste than the model might have predicted. More productive waters are recognised as being less affected by additional nutrient loads (Costa Pierce, 1994).

Widening the discussion beyond the above case, similar input output models have been used in assessing impacts of fish farms discharging wastes into rivers. In marine sites, the carrying capacity is often dependent more on changes in the benthos than in the water column, although where there is extensive development, or very enclosed sites, water quality impacts may be important. A range of modelling approaches for predicting benthic impacts have been reviewed by Barg (1992) and Beveridge (1987).

It must be noted that these predictive tools are simplistic, and for certain impacts, there remains considerable uncertainty over the fate of wastes. For example, while hydrographic models may be applied to predict dispersal of chemicals, which may indicate rapid dispersal to below detectable levels, this does not necessarily mean that these will have no impact: this might be of particular concern where there is potential for

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[1] while in this case the former assumption holds, phosphorus did not appear to limit productivity: ie the levels of inputs were beyond the operational boundaries of the model.

bio-accumulation. Similar uncertainties exist in the case of the biological impacts of antibiotics.

Accepting the limitations of predictive modelling, these approaches still represent important tools, and while perhaps limited in accuracy, do allow broadly representative assessments of many aspects of impact to be made. However, for this to contribute to the assessment of sustainability there is also a need for appropriate criteria by which "acceptable levels" of impact can be established in a specific context. This will generally depend on the initial characteristics of the environment, and the other users or uses of that resource. Some general attempts at classification of fresh water bodies according to productivity and criteria for a range of uses, as given in Table 5.7.

Table 5.7 Proposed water quality criteria for different uses

Use	**Criteria** [P] μg/l	**Comments**
drinking water	<10	oligotrophic waters preferred; in general no increase in productivity acceptable
contact water sports	<10	oligotrophic waters preferred
salmonid fish	<10 ...20	< 10 optimum; up to 20 acceptable
coarse fish	20-200	.. but variable
irrigation water		no limits
power generation		no limits
intensive salmonid cage	<10...20	< 10 ideal, up to 20 acceptable, >20 increasing risk
intensive carp cage/pen culture	< 50	ideal
semi intensive carp/ tilapia and extensive carp /tilapia, milkfish	50-100 ?	wide tolerance; depends on management of oxygen levels

(adapted from OECD 1980 and Beveridge 1984)

5.8 Overview of sustainability issues

The main theme of this chapter was to presented a detailed investigation of the interactions and feedbacks between a specific farming operation and the culture environment, in the context of indicators of environmental condition and production performance, and sustainability from the point of view of the investor. The availability of methods for predicting such impacts, and their use in the decision making process, was briefly discussed.

In setting criteria for allowable levels of discharge or change associated with a specific activity, it is important that this is clearly set in the context of other present and potential future sources of similar impacts on the same ecosystem. For example, problems of coastal enrichment are of growing concern in many regions of the world, with impacts on ecosystems structures and functions, feeding through to coastal economic activities, such as fisheries and tourism. One of the most dramatic developments associate with such changes is the increasing global incidence of "red tides" and associated impacts on both human health and wildlife (Anderson, 1994; Falconer, 1993). In this context, development of intensive aquaculture operations might contribute to such problems. However, if new developments are not considered in context of other users and impacts, potentially beneficial developments (on social and economic criteria), could be prevented for the wrong reasons, representing missed opportunities for diversification.

The main points which arose in this chapter were:

- there are a range of indicators of environmental change associated with waste outputs from fish farming operations, which can be modelled to provide a broad assessment the potential impact on the farming operation and other resource users. In the case study above, the impacts detrimental to the fish farming activity may have benefitted some other resource users (anglers).

- uncertainty and complexity of the systems involved limit the accuracy of predictive models of changes in water quality, but they can serve to provide reasonable guidelines of the potential scale of impacts. In addition to predicting impacts, ongoing monitoring represents an important aspect of impact assessment and can provide information which can be used in adaptive management to reduce effects of negative feedbacks in the system. The monitoring requirements must be set within the context of perceived information needs and risks, and costs of gathering that information. Having gained an understanding of the system interactions, there is the potential for relatively simple indicators to replace more detailed monitoring. In this above case these include aspects such as routine monitoring of temperature and oxygen levels, observations of changes in water colour in relations to weather patterns, and routine recording of stock performance (growth and losses).

- management systems have to deal with a wide range of often conflicting information and needs, which may lead to decisions being taken which appear to go against the longer term objectives (in the above case that of financial sustainability) .

- unsustainability at the commercial level due to self induced environmental impacts does not necessarily imply unsustainability in broader environmental terms, although in the above case the level of analysis did not specifically address wider sustainability issues.

- the selection of criteria for acceptable levels of change, and the relevance of such information in the analysis of sustainability, is part of the management/ political process which must be set in the context of other resource users.

- there is a need for valuation mechanisms by which the environmental effects of alternative economic activities can be equated in terms of defined benefits

Chapter 6

Case study 2

Energy valuation as a sustainability indicator

Chapter 6 Case study 2: Energy valuation as a sustainability indicator

6.1 Introduction

The previous case study illustrated the conflict between short term financial objectives and long term survival of a production process: the influence of the fish farming operation on the environment which sustained it was not fully accounted for in the business planning process, and resulted in negative feedbacks with significant implications for the commercial sustainability of the business. The potential significance of wider impacts of this production process were indicated, but not explicitly measured. Where activities operate on a wider local resource base, the influence of production processes on the environment may be less obvious, and the direct feedbacks less critical to the business. In these circumstances, while the criteria of viability set by the market place may well be fulfilled, there may be hidden costs in terms of use or degradation of the resource base, either in terms of provision of inputs, or waste processing capacities for outputs. An analysis based on criteria which takes account of this wider, or longer term perspective, may not suggest the same level of viability.

Two important aspects of resource use efficiency on the input side concern the conversion of available natural productivity into human food, and the level of dependency on limited, non renewable fossil energy resources. The objective here is to consider techniques of resource analysis expressed in energy terms, in assessing resource use efficiency, and hence potential sustainability. Energy, as a basic natural resource, driving force and indicator of thermodynamic quality, has been widely acknowledged as a generalised 'numeraire' or quantitative indicator of efficiency of resource use and transformation (Slesser, 1974, Odum HT, 1983; Odum, E.P, 1989): in general terms, returning to earlier sustainability discussions, conversion of renewable and non renewable natural capital to other goods and services might be assessed, using energy as a numeraire, on a unified comparative basis. This chapter is developed by-

- considering the rationale for using energy as a numeraire in assessment, and presenting an overview of different systems boundaries and approaches to energy analysis.

- presenting a detailed case study on the application of one approach, Industrial Energy Analysis (IEA), to a range of aquaculture systems

- discussing the potential of IEA as a tool for sustainability assessment at a range of levels.

- considering briefly the wider boundaries for energy analysis in the context of renewable resource use assessment.

6.2 Resource use assessment: Energy as a numeraire

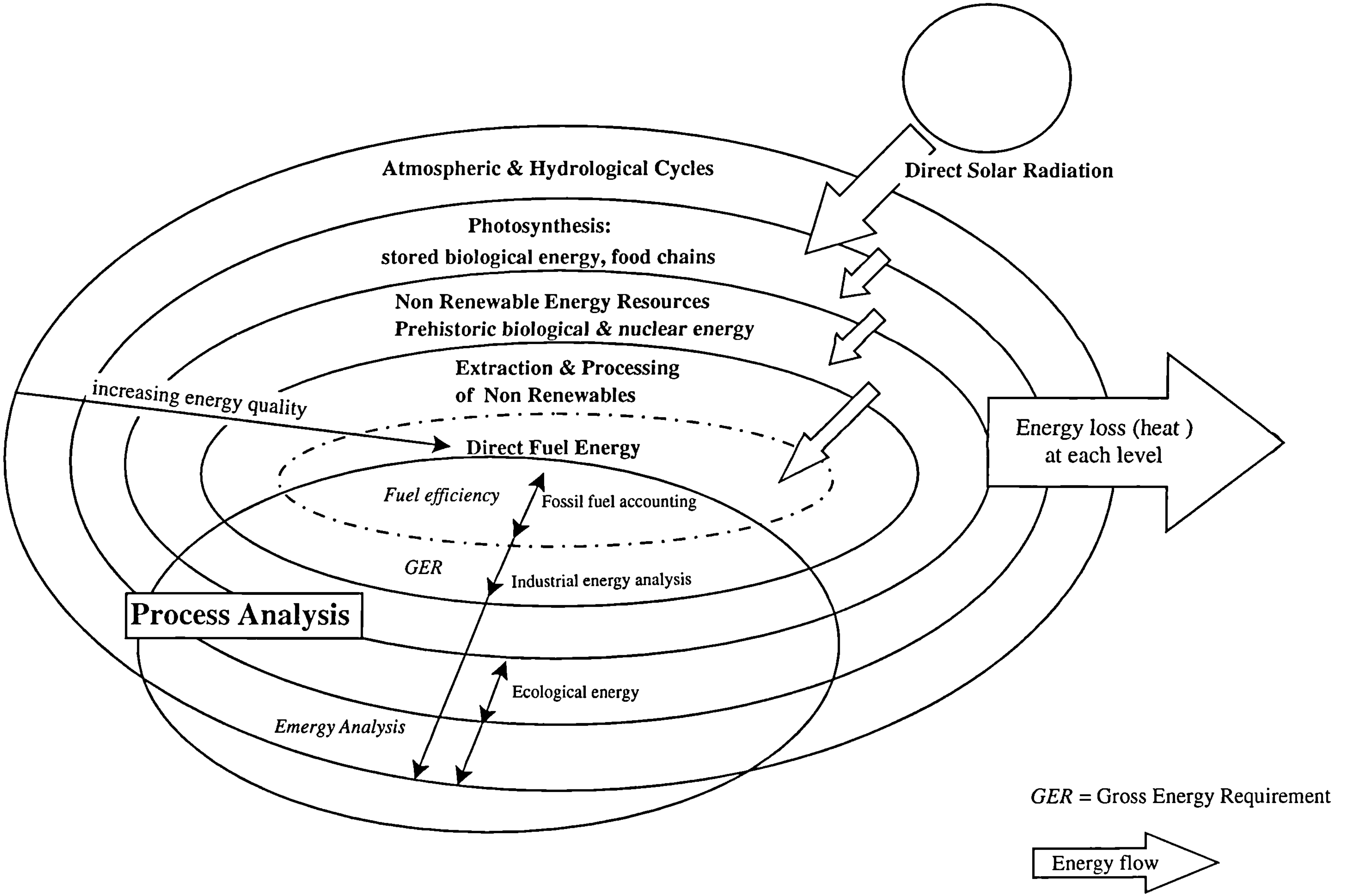
6.2.1 Basic concepts, energy sources and systems boundaries.

In considering "energy" as a common unit for assessment, it is important to establish what is being measured, where the system boundaries of the analysis lie and ensure clarity in terms of disciplinary definitions (eg those of the physicist, engineer or ecologist). In a general context, Chapman and Roberts (1983) describe energy as "a concept or an idea, rather than a thing or substance: it is the name given to the property of a system which changes when the system exchanges heat or work with its environment or another system". The behaviour of energy is described by the laws of thermodynamics[1]: the first states that energy may be transformed from one type to another, but never created or destroyed. The second law is concerned with energy changes. This states, in simple terms, that all energy transformations and storages involve some energy being degraded to unavailable or less available forms (eg heat). The "availability" is defined in terms of the level of disorder, or entropy in the system: low entropy describes a highly ordered, high energy utility state, and high entropy the converse. These laws mean that the maintenance of highly ordered (low entropy, or far from equilibrium) systems (eg organisms , ecosystems) requires energy inputs, and will involve energy dissipation (to lower utility, higher entropy states, such as heat).

Taking a global perspective, life on earth (the biosphere) represents a low entropy system, powered by the incident solar radiation (Figure 6.1). Through photosynthesis,

[1] for a theoretical background see Odum (1983), Chapman and Roberts (1983) and Odum, E.P 1989).

Figure 6.1 **System boundaries in global energy and process analysis**



assisted by atmospheric and hydrological processes, plants (producers of biomass) harness the energy of the sun, which drives the transformations of matter into more highly organised, lower entropy states. This represents a store of energy, which is then available to consumers of plant materials, and so on up the food chain. In this transformation, a proportion of the energy is dispersed as heat (and potential for work is "used up"): thus it takes about 100 solar calories (cal) to produce one cal. of energy stored as plant material. In each transformation through subsequent trophic levels, from plants to herbivores to carnivores, about 90% of the stored energy is dissipated as heat giving a transformation efficiency of about 10:1. This relationship determines the structure of ecosystems, in terms of the decreasing relative biomass of plants, herbivores and levels of predators.

In ecological systems analysis, Odum (1989) has described this transformation process in terms of energy going through "changes in form... becoming increasingly concentrated or very high in information content. In other words as the energy quantity decreases, its 'quality' increases". Here the concept of quality or concentration has been related to that of embodied energy, which is a measure of transformation efficiency, or "the ratio of one type of energy required to develop another type" (Odum 1989). Thus it has been calculated that it has taken about 2000 units of solar energy to produce 1 unit of fossil fuel energy. In ecological energetics quality and work are also used to describe systems information, and the potential for control and feedbacks within systems: thus the higher up the food chain, the lower the quantity of organisms, but the greater the extent of feedback and control exerted on lower levels (e.g. carnivores on herbivores on plants) essential in maintaining the organisation and function of the system (Odum, 1983).

In physics and engineering, the term concentration and quality applied to features of energy is concerned with the work potential of the given energy source, or free energy, rather than the efficiency of transformations by which that source has been produced. Thus Boustead and Hancock (1979) define energy concentration as "the maximum amount of energy which can be extracted from a given amount of material in a specified state".

A final definition relevant to the following analysis is that of IFIAS (1974), which distinguishes system energy inputs in terms of "flux sources" (renewable, such as solar, hydrological cycles) and "resources" (non renewable sources or energy stores). Thus flux sources provide energy over an extended period of time, and are limited by the rate of supply, rather than the quantity of the source; resources offer a finite amount of potential work related to their stored quantity and energy quality (free energy), where fuels release their energy through chemical reaction (coal, oil, gas, etc) or transformation (uranium 235 etc). While the term 'resource' could also refer to biomass, such as timber, in a longer term perspective such resources are also essentially flux sources. Thus there is potential for confusion in some aspects of these definitions, which may be related to both time span of the resource formation (generational for forests versus geological for fossil fuels), and may also relate to the potential for human action and control (eg in terms of planting a forest for future fuel source).

The relationship between different energy sources used by human activities in industrialised societies is that the natural energy concentrating (entropy decreasing) processes of the ecosystem, driven by flux sources, are often supplemented with high quality energy resources derived from fossil fuels (past products of solar energy inputs).

6.2.2 The rationale for energy as a measure of value

The lack of value attached to natural resources in the industrial economy, a central issue for sustainability, was highlighted by Schumacher (in Gilliand, 1975) who argued that

> "production depends heavily on the capital provided by nature in the form of air, water and resources" and that "we treat this capital as income and value it at nothing"

Furthermore, where modern society does place a "value" on the resources used in human endeavour, the economic criteria used are subjective, based on scarcity (supply) and perceived needs and wants (demand). Values are based on the effort required to obtain, not an intrinsic value of the resource, and are not constant spatially or temporally: the further into the future, the more difficult economic forecasting becomes, particularly if discount rates are applied (see earlier). In seeking a more objective and fundamental measure, Slesser (1974) identified two criteria of value: economic and energetic, and proposed that while "the former fits well into ones personal equation of advancement; the latter better fits the needs of global society". Here he noted that energy is "the only commodity in ultimate limitation when employing a long time scale", and as discussed above, is fundamental in creating and maintaining order in living systems. Theoretically, all other resources can be replaced or reconstituted given time and energy: they can be changed in form and concentration, not created or destroyed. Energy, on the other hand, providing a driving force for work, can only be used once. The rationale for energy as a measure of value is explained by King (1987):

> "Because energy is required for all economic processes in accurately specifiable amounts, it can serve as a common unit of currency, linking inputs and outputs within and between different sectors of the economy" .

The idea is not new. The link between energy and economics, and the concept of energy as a measure of value, was identified at the turn of the century (Soddy, 1912, in Thomas, 1977). In the late 1950s the concept of energy as a measure of utility and work provided by nature, was used by Odum et al (1959) to value the contribution of estuarine ecosystems to the economy. Odum (1983) highlighted the ecosystem -economy relationship as follows:

> "where humans are part of the (eco)system, there are economic transactions and flows of money. Economic behaviour of human beings causes money, a symbolic form of information, to flow counter-current to the flow of commodities bearing energy"

In the 1970s, forecasts of global energy shortages stimulated research into evaluation of industrial production in terms of non renewable energy "costs" of alternative products and processes (Chapman, 1974). By the end of the 1980s a new reason for popular concern over energy consumption was emerging: global pollution and climate change. The energy costs of production therefore involve not only sustainability issues of ecosystem resource efficiency and non renewable resource depletion, but also the potential cost to future societies through environmental change.

6.2.3 Approaches to energy analysis

There are several related approaches to energy analysis, based on similar concepts, involving slightly different methodologies and areas of application. The main difference between approaches relates to the energy systems boundaries applied, illustrated in Figure 6.1. This highlights different types (and qualities) of energy inputs to natural and human production systems. The most simple level of energy analysis is concerned with direct fuel efficiency of a process, with the objective of improving financial performance through reduce fuel costs. Widening the boundaries of analysis involves the more fundamental properties of energy and considers the energy used up in driving all processes leading up to and including the specific activity. In these terms two principal approaches can be identified, one setting the boundaries at the level of fossil fuel energy, or non renewable natural capital, the other including renewable natural capital: the resources and flux sources defined by IFIAS (1974) above.

The analysis of non renewable energy resources used in industrial and other processes, including the increasingly energy intensive food production systems of the "green revolution", originated in the 1970s. The resulting methodologies were termed "energy analysis", or "industrial energy analysis", measuring "energy subsidy" (Slesser, 1973) and later "Gross Energy Requirement" (GER). The latter, proposed by IFIAS (1974), was defined as "the sum of all the energy sources that must be sequestered in order to make a product available", or as explained further ...

> "The value of GER is the gross enthalpy released at a standard rate of all the naturally occurring energy sources which must be consumed in order to make a good or a service available. The systems boundaries are set at the point of extraction of the raw materials, including the energy resource itself, as defined above, and includes all the energy (fossil fuel equivalent) to drive the industrial processes through manufacture of the machinery and products which are used as inputs to the system, in addition to direct fuel energy to drive machinery".

Flux sources are not included, except where some energy resource might have been used to harness that source (eg manufacturing of solar panels), the rationale being that as renewables they are not critical to the longer term continuance of the system. Units are based on the fossil fuel equivalent, in terms of energy units per unit produced (eg GER in GJ/tn). IEA has been applied to a wide range of food production processes, including agriculture, livestock, aquaculture and fisheries. In an early paper proposing the measure of "energy subsidy" (or GER) as a tool for food policy planning, Slesser (1973), outlined the boundaries of analysis as follows:

> "Natural food production is a photosynthetic rate process, in which the capture ratio for solar energy is comparatively low. In systems where man intervenes the ratio is normally higher. The intervention takes the form of work done, whether it be to the soil, the crop, in preparation, irrigation, fertilisation or harvesting. Each of these activities has an energy content, which may be readily computed and is called the energy subsidy".

The additional work done represents a form of system feedback discussed earlier, where a high quality energy source can influence the efficiency of the system in utilising lower quality forms of energy. The same basic principles apply to livestock production, with natural systems limited by the primary productivity in the food chain supporting the production. Similarly, the productivity can be increased by altering culture environments and supplementing food sources, which also represent energy subsidies to the system.

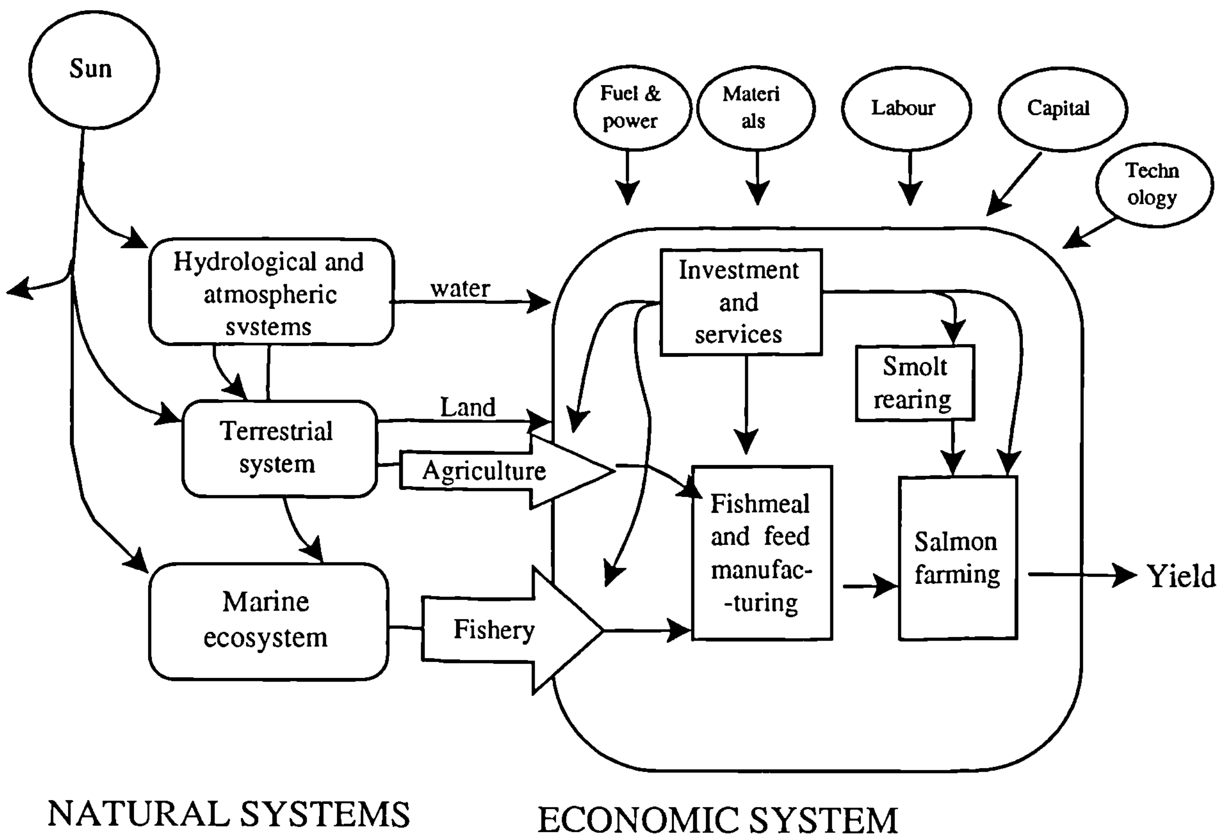
Based on similar concepts, but widening systems boundaries to include flux sources and biological energy transformations, ecological energy analysis is concerned more with the renewable resource components of the system. As such it is more clearly defined by ecological relationships and their operation and efficiency (Odum, 1983; Odum, 1989).

Related to the above methods, the process of emergy (<u>em</u>bodied en<u>ergy</u>) analysis developed from studies of the energy relationship between ecosystems and human economic activities (Odum, 1988). This measure is based on the solar energy equivalents of all energy sources entering the system, and includes both renewable and non renewable sources; it extends the boundaries beyond those of most ecological energy analysis to include embodied energy of atmospheric and hydrological processes. Odum has also proposed that the emergy of products can be used as a measure of value of goods and services flowing within the human economy: this is similar to the concept proposed by Slesser (1973), but, by extending the boundaries beyond fossil fuel use, recognises the limited nature of renewable resources. This is discussed in more detail later.

Energy analysis of aquaculture systems

The ecological and economic systems supporting an intensive fish farming operation are illustrated in Figure 6.2. The range of inputs involved will vary with the type of aquaculture, but come under the same broad categories: capital, technology, materials, feeds and/or fertilisers, auxiliary energy and labour. There are also the environmental contributions, in the form of solar energy driving primary productivity and hydrological cycles. The focus of this chapter is the application of industrial energy analysis (ie embodied fossil fuel energy) to a number of aquaculture systems, set within the economic system boundaries of Figure 6.2. The analysis of energy at the wider, ecological system boundaries, and the importance of the linkages between systems and with other views of these systems is considered later.

Figure 6.2 Natural and Economic systems involved in intensive salmon production



(adapted from Folke 1989)

6.3 Industrial energy analysis of aquaculture systems

6.3.1 Background

This case study aimed to develop a spreadsheet-based tool for combined financial and energy analysis of aquaculture production systems. Examples were selected to represent a range of systems, and included intensive salmon and mussel culture operations in Scotland, semi subsistence pond fish culture in Malawi, and intensive cage fish culture in Indonesia. Data for Scottish case studies were collected from commercial operators, suppliers to the industry and trade and academic literature. The Malawi case data was obtained during field work in 1986, while the Indonesian case is based on a UNDP 'package technology' provided by FAO, Rome (FAO, 1986). The method was initially developed from a component of a study commissioned by the FAO (Stewart, unpublished).

6.3.2 Methods

The models were developed using a Lotus 123 spreadsheet package. The energy modelling was based on a financial appraisal model which provided cost and return per unit of production and, where appropriate, Net Present Value (NPV) and Internal Rate of Return) IRR. Adaptations for energy analysis involved the calculation of energy worth of inputs (Joules) to determine the energy cost (or GER) per unit of output (expressed in MJ/kg of whole product, edible meat, and edible protein). This required the breakdown of major inputs into material specifications, to which energy values could be attributed. Energy "costs" were calculated in a similar manner to financial costs: capital inputs were allocated to production cycles over the life of the item by straight line depreciation, while operating inputs were allocated to annual production periods.

Labour input is a particularly contentious item. At one level there is the actual energy required to contribute to the production process (metabolic energy of individual work), although the embodied energy in the food required to produce that work energy will depend on the type of food and production systems used. At another level it is reasonably argued that the total energy of life support, related to average material standards of living, should be included, which could be 70 times greater than the nutritional energy (Fluck, 1976, in Storck, 1978). A number of authors have quantified this by salary, on the basis that there is a close relationship between GNP and energy use (see Cleveland et al., 1984; Costanza, 1980; Gilliland, 1975). The approaches used in the literature range from not including labour (eg IFIAS, 1974; Storck, 1978), to the above "life support" values. The impact of such differences in approach to valuation of labour have been discussed by Kumar and Twidell (1980). In this study, labour was not included in the base case analysis, although the model structure allowed labour energy costs to be included, the impact of which could be demonstrated.

Details of the model structure and assumptions used are described in Annex 2. The allocation of material energy values, and relevant references, are presented in Annex 3. A fully worked example, as applied to an intensive salmon farming system, including technical specifications and assumptions, is given in Annex 4. The only modification required in applying the model to different production systems was to allow for the different capital and operating requirements, and different production periods.

6.3.3 Results

Results are summarised in Table 6.1. This includes system data, energy cost per unit output and comparative contributions of capital and operating inputs to both energy and financial costs. The impact of including different approaches to valuation of the energy cost of labour is illustrated. It must be noted that the energy costs of whole and edible product, and edible protein, do not demonstrate a consistent relationship for different species, due to varying dress-out weight and protein content assumptions (TDRI, 1981). Comparisons of GER values for other animal production systems is presented in Table 6.2, later. Results are presented under three sub-headings: intensive and semi-intensive systems, and intensive mussel production.

Table 6.1 Energy analysis of aquaculture systems: summary of case study results

Species, location System details	Salmon, Scotland Intensive, commercial marine, cages			Grouper/ bass, Indonesia Intensive, commercial Marine, cages			Mussels, Scotland Intensive, commercial marine, ropes			Tilapia, Malawi Semi-intens., semi-subsistence Ponds, fresh water		
Production data												
Av. prodn cycle	2.5 years			0.5 years			2.5 years			0.5-1 year		
Steady state output	200 tonnes /yr			3.6 tonnes /yr			100 tonnes / yr			58 kg / yr		
Average annual (10 yrs)	175 "			3.4 "			85 "			58 "		
Kg/labour day	100 kg			12 kg			170 kg			5.8 kg		
Site area	0.5 ha			0.01 ha			2 ha			0.005 ha		
GER MJ/kg												
Whole product	**99**			**144**			**4.6**			**24 ***		
Labour sensitivity	+metabolic	+0.01%		+1.2%			+1.6%			+17%		
	life support	+18%		?			+326%			?		
Edible product (MJ/kg)	142			262			11.6			40		
Edible protein(MJ/kg)	688			1311			116			199		
Financial and energy cost structure	(% cost per unit output)											
		cost (£)	GER		cost (£)	GER		cost (£)	GER		cost (£)	GER
CAPITAL ITEMS	Offshore structures	5%	5%	Offshore structures	5%	2%	Offshore Structures	5%	40%	Pond		
	Equipt	2%	< 1%				Equipt	7%	5%	Labour	35%	na
	Onshore Structures	<1%	<1%				Onshore Structures	4%	8%	other	3%	3%
	Vehicles	<1%	<1%				Vehicles	3%	5%			
SUB TOTAL		**9%**	**6%**		**5%**	**2%**		**18%**	**58%**		**38%**	**3%**
OPERATING ITEMS	Feed (+transport)	36% 0%	79% 4%	Feed	45%	78%				Feed	56%	97%
										Stock	na	na
	Stock	23%	3%	Stock	9%	10%	Labour	63%	na	Labour	na	na
	Labour	14%	na	Labour	10%	na	Fuel & power	4%	42%	Fertilisers	3%	na
	Fuel & p	1%	4%	Fuel & power	22%	7%						
	pst.harvest	4%	3%									
	others	12%	1%	others	9%	3%	others	15%	<1.0%	others	3%	0%
SUB TOTAL		**91%**	**94%**		**95%**	**98%**		**82%**	**42%**		**62%**	**97%**

* If GER feed = 0, total = 0.7MJ/kg

Intensive aquaculture systems

Two cases were examine: salmon production in Scotland and grouper/ seabass production in Indonesia. In both cases financial and energy costs (GER of 99 and 144 MJ/kg whole product for the two systems respectively) are dominated by operating inputs, at over 90% of the total, of which feed is the single most important item. This item also represents the main difference between the financial and energy criteria, with feed representing almost 80% of total GER, compared with 40% of total financial costs. The higher energy costs per unit output of whole product of the grouper/ seabass system (Annex 5) in comparison to salmon (Annex 4) is related largely to the assumptions concerning the GER of feed[1].

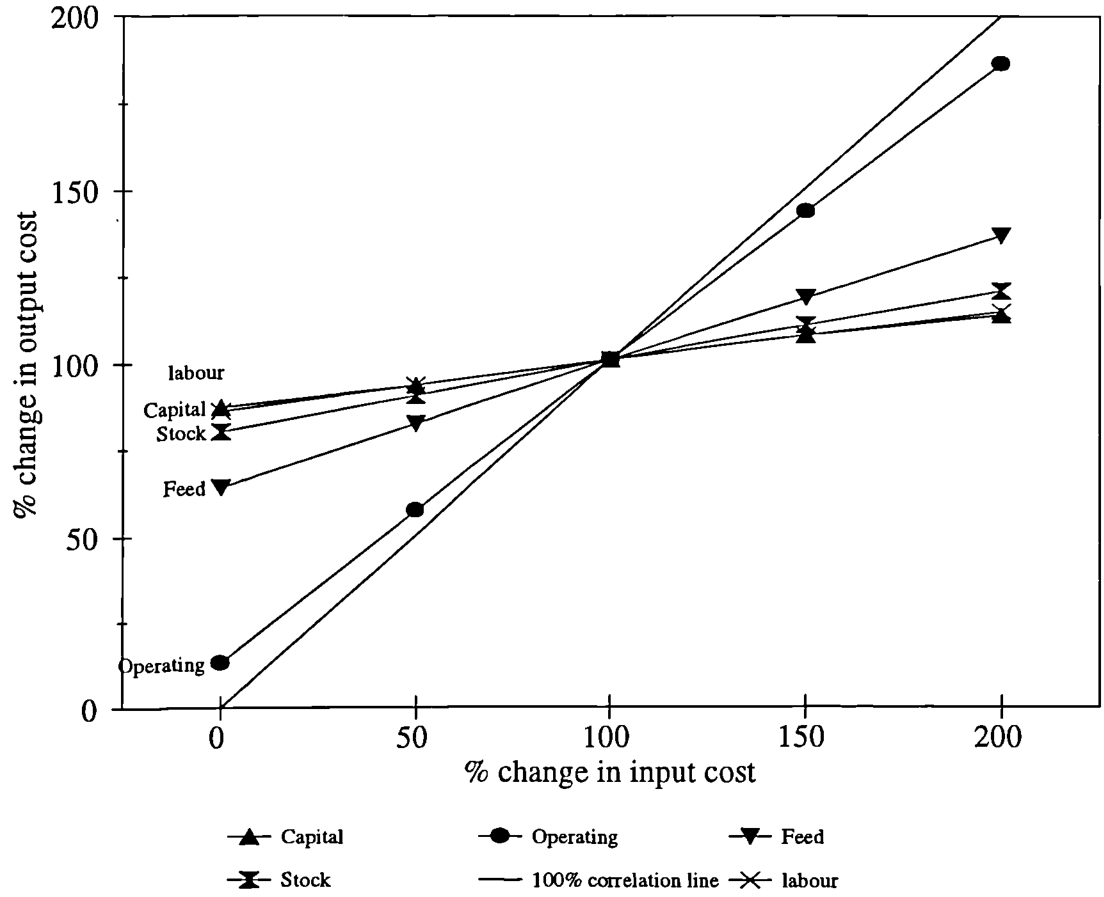
The sensitivity of this model (demonstrated in Figure 6.3 for the salmon case), and particularly the energy analysis, is therefore dominated by feeds: a 50% increase in the GER of this item (either through GER content, or food conversion efficiency) increases the GER of the final product by about 40%. The models are therefore relatively insensitive to changes in other capital and operating inputs: apart from feed, no single item or item class accounted for more than a 5% change in total GER following a 50% change in the conversion value applied.

The effect of different approaches to accounting for labour in energy analysis is illustrated in Table 6.1. In both intensive fish culture systems the inclusion of the metabolic labour energy makes no significant difference to the output GER, even in the more labour intensive tropical system (production of 12 kg/labour day, cf salmon 100kg/labour day). Including an allowance for GER of labour in terms of life support, related to the salary costs of production, does, however, have a significant impact in the intensive salmon case, increasing the GER by about 18% (data was not available for the other, but may be assumed to be rather lower).

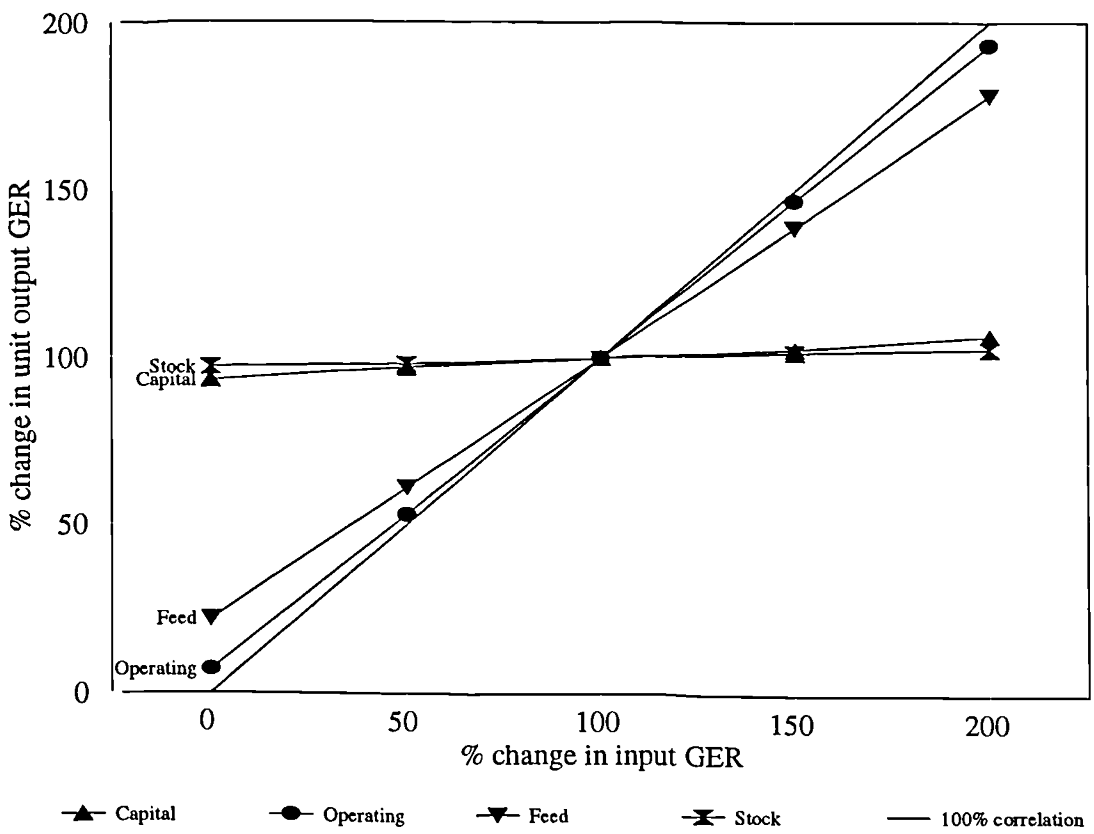
[1] This difference increases when these systems are compared in terms of protein produced, due to the higher edible meat yield from salmon (see Annex 3).

Figure 6.3 Sensitivity analysis for financial and energy costs of salmon production

6.3a Financial cost sensitivity



6.3b Energy cost sensitivity



These results suggest that although the convention for labour cost must be made clear, the GER estimated for fish feed is most critical. This in turn is dominated by the GER of the fishery derived component of the diet[1] (see Annex 3), which in turn is determined by the fishing methods used to catch these fish (Edwardson, 1976b). The type of fish stock, changes in the abundance, and changes in fishing methods are the main sources of variation in the energy costs of fishery products. Hence the energy cost of intensive aquaculture relying on sea fisheries will be subject to the same variability. In this respect, it is important to note that the analysis does not attribute a value to the resource base; the marine fisheries. Although this is heavily exploited, and limited in its ability to renew under increasing fishing and environmental pressures, it is commonly considered a "free resource", and so it is only the energy sequestered in the capture and processing which is considered when accounting for the GER of fisheries products. This aspect is discussed later.

Semi-intensive systems

Extensive and semi-intensive fish culture systems rely on natural productivity of the pond environment and in the latter case, supplementary feeding and fertilisation. This covers a wide range of systems, from subsistence level to larger scale commercial operations. The former can be simply a hole in the ground into which household waste can be thrown, and although productivity (production per unit area) may be very low, the investment is also low. Commercial semi-intensive systems can range from the small business farmer, selling from the pond side, to the corporate business producing for international markets.

The example here is of a small scale semi subsistence operation in Malawi (a summary of the case is presented in Annex 6. Further details of this type of system are considered in Chapter 7). Small ponds of a few hundred square meters are typical of most smallholder fish farmers in rural Malawi, and other countries of the region. Relatively labour intensive (here yields estimated at about 6kg per labour day) the system generally relies on low cost, or on-farm and household sources of feed and fertiliser. Restocking is achieved from the farmers own stock, having obtained initial stock from government

[1] the inclusion rates vary for different species.

hatcheries or neighbouring farmers. No financial or energy cost is assumed for these fish, although given the initial source this is a slight simplification.

The base case suggests that GER per unit output (at 24 MJ/kg whole fish) is about 25% of the GER of salmon, although in some circumstances, this system may incur no industrial energy costs. As feed is the only operating input with notable industrial energy content, this represents 97% of the total energy cost[1]: a sensitivity analysis will therefore be dominated by this to an even greater extent than in the intensive systems.
The assumptions made in attributing energy values to feeds are again critical. This can cause significant problems on two counts: firstly, where crop and animal by-products are used, the allocation of energy value between the main product and the by-product does not appear to have been dealt with in any systematic manner in the literature. This is considered further below.

Secondly, although the same feeds might be used, the associated energy costs will vary with the agricultural system from which it was derived. For example, a farmer might purchase feed (maize bran) derived from hybrid maize, grown with artificial fertilisers and milled in an industrial plant, incurring a range of industrial energy costs. Another farmer, however, might grow local maize, with no chemical fertilisers, which is processed on the farm, producing maize bran with almost no GER. An integrated farming system, which does not rely on imported fertilisers or feeds, and uses only human and animal labour, may incur little or no industrial energy costs in fish production.

The inclusion of metabolic energy of labour in the base case increases the total GER by about 17% (cf less than 0.1% in the case of intensive salmon). Including the GER of life support would have an even greater impact, although the per labour day value would be extremely small in comparison to that for developed countries. It could be argued that the GNP related figure would be more applicable to the more developed sector of the country, and that rural farmer's energy demands would be closer to the metabolic levels.

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[1]The model here allows a small energy allocation for manufactured tools which gives a GER of less than 1MJ/kg whole fish, when no energy costs for food or labour is assumed.

Finally, the financial costs in this case are dominated by feed in the operating costs, and labour for pond construction in the capital costs. However, in practice, pond construction may occur using family labour, with no opportunity cost. Similarly, pond productivity may be derived from available inputs with no financial or opportunity cost. The problems of valuation of semi-subsistence, integrated aquaculture systems is considered in more detail later.

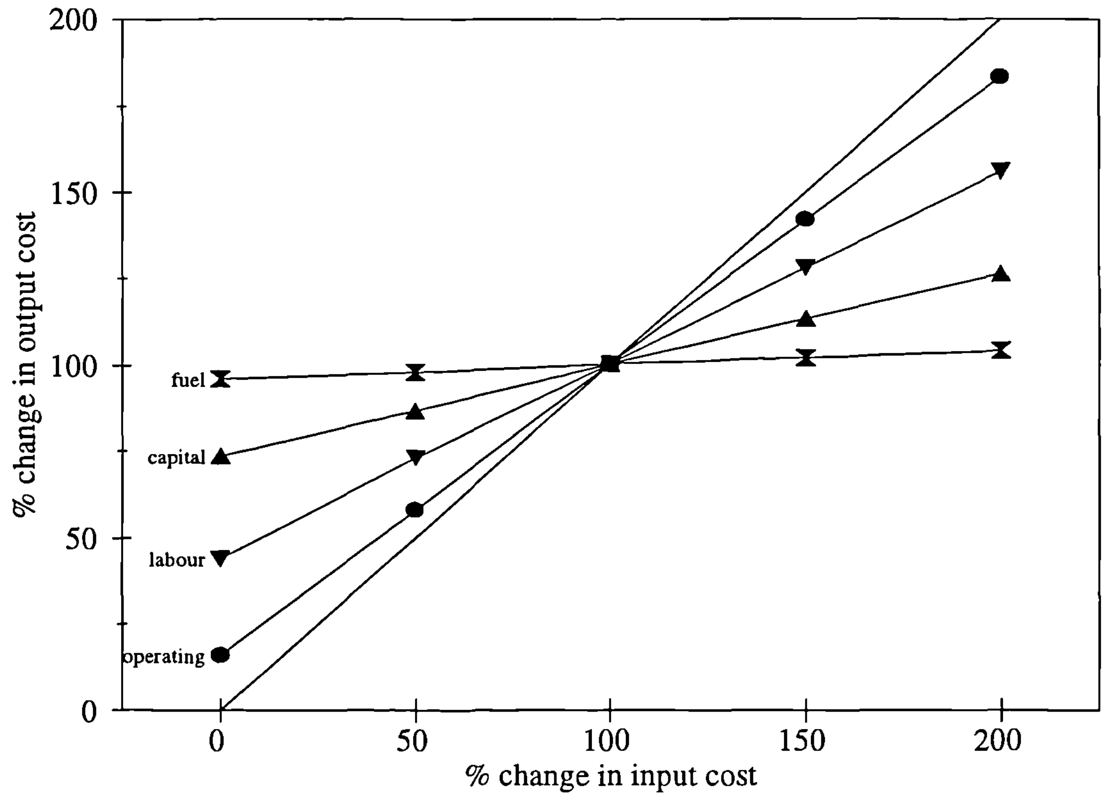
Intensive mussel production

The key feature of the culture of bivalve molluscs is that the growth of these animals relies on the filtration of naturally occurring feed from the culture environment. Intensive culture refers here to the degree of management, and capital investment in structures and equipment. The Scottish example presented in Annex 7, summarised in Table 6.1, suggests that the GER of mussel production, at 4.6MJ/Kg whole product, is about 4% of that of salmon. In terms of protein produced, this figure increases to about 17%, due to the lower edible proportion of mussels (40%, cf 70% in salmon), and the lower protein content of shellfish flesh (10%, cf 20% salmon, TDRI, 1981). A sensitivity analysis for this case is presented in Figure 6.4.

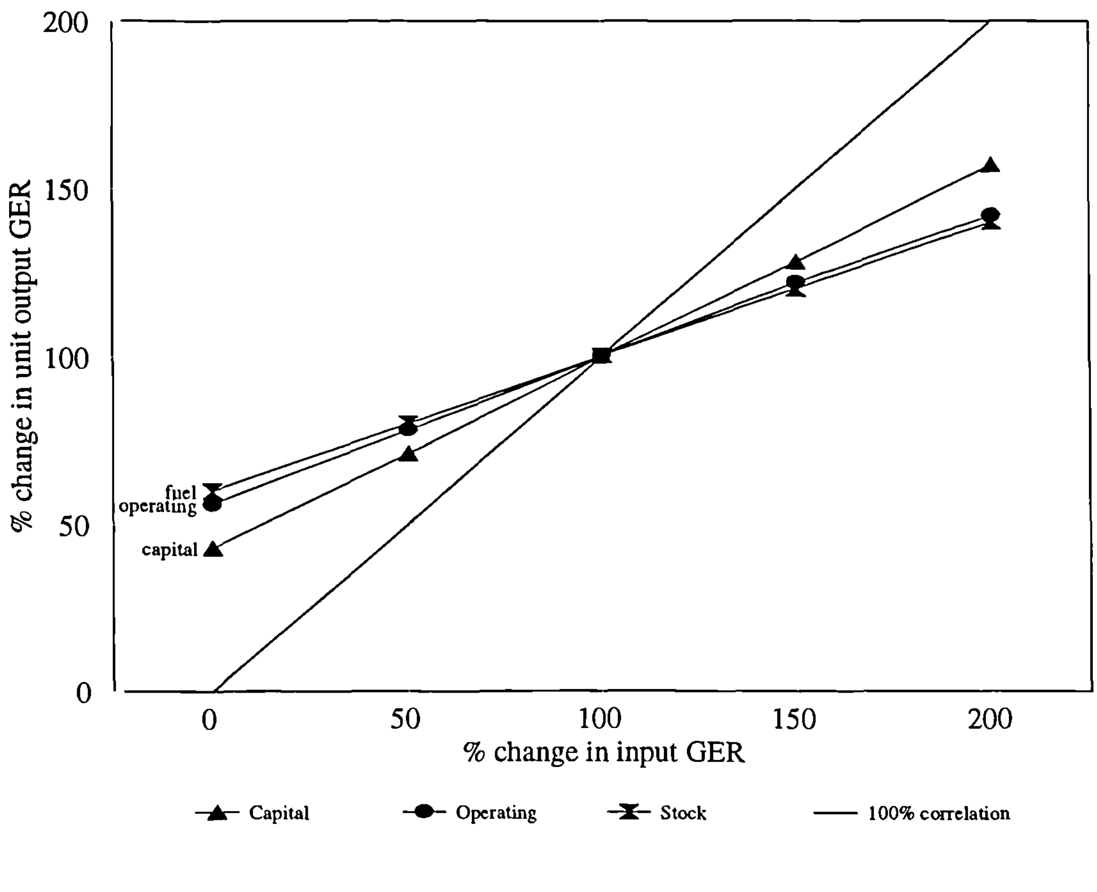
The energy cost here is dominated by the capital items, the remainder being associated with direct energy costs in the fuel and power. This is due largely to the absence of feed, which accounted for most of the GER of fish production. Financial production cost is dominated by labour, representing more than half of the total. The rest is represented equally by capital and other operating costs. The inclusion of labour in terms of metabolic energy is again insignificant. However, if a salary related estimate for the energy cost life support is included, this increases the total GER of mussel production to more than three times.

Figure 6.4 Sensitivity analysis for financial and energy costs of mussel production

6.4a Financial cost sensitivity



6.4b Energy cost sensitivity



6.3.4 Comparison with other livestock

Comparative energy costs of livestock and crop production systems have been the focus of considerable research since the 1970s (see Pimentel and Pimentel, 1979; Rawitscher and Mayer, 1977; Pimentel, 1980; Giampietro et al., 1992). A selection of examples, and the data for the above cases, are presented in Table 6.2. A particular feature in the aquaculture industry, not so readily apparent in other livestock production systems, is the wider range of trophic levels involved. Terrestrial livestock production involves primarily herbivores and omnivores, while aquaculture also involves the production of carnivorous species, requiring a very high proportion of animal protein (typically fish meal) in the diet. At the extremes represented by salmon and mussel production above, trophic level is clearly a significant factor in the total energy requirement.

Table 6.2 GER of a range of livestock production systems

Product	Production system	GER MJ/kg protein	Source
AQUACULTURE			
Case studies:			
Mussels	Intensive, long-lines	116	a
Tilapia	Semi-intensive, ponds.	0-199	a
Salmon	Intensive, cages	688	a
Grouper/ Seabass	Intensive,cages	1311	a
Other studies:			
Polyculture (Carp/ tilapia)	Semi-intensive, ponds	271	b
Catfish	Intensive, ponds	582	c
Catfish	Intensive, raceway	3780	d
Carp	Intensive, recirculated	3090	e
OTHER LIVESTOCK			
Beef	Pastoral	0	f
	Rangeland	170	c
	Feedlot organic	234	f
	Feedlot closed	513	f
	Feedlot open	1143	f
	Feedlot open	1350-3360	c,g
Lamb	Rangeland	170	c
Pork	Intensive	595-718	c,g
Poultry	Broilers	370	c

Sources: derived or adapted from: a: Case studies above; b: Bardach, 1980; c: Pimentel and Pimentel, 1979; d: Rawitscher and Mayer, 1979; e: Edwardson, 1976a; f: Giampeitro et al, 1992; g: Rawitscher and Mayer, 1977.

However, it is apparent from the range of systems illustrated in Table 6.2, that trophic level does not necessarily predict industrial energy costs; these are determined by a range of other factors, including the intensity of the production process, the energy required to provide feeds and the degree of mechanisation and environmental control in the husbandry system. While in the earlier aquaculture examples capital and non feed operational energy inputs were relatively small, in some highly intensive aquaculture systems, mechanisation (eg aeration and pumping in intensive recirculated systems) can significantly increase total energy costs.

The importance of the source and means of production of feed on the GER, demonstrated for aquaculture systems above, can also be observed in other livestock systems. For example, Giampietro et al (1992) has examined feedlot beef production, comparing energy subsidy required for open, closed and organic systems (see Table 6.2). Open systems rely on the importation of feeds (grains) from other production systems, the energy requirement being determined by the type of production process and transport distance from the source. On the basis of available data, some of these appear to be significantly more energy intensive than the cage based salmon production systems considered above, similar to figures for some of the more highly mechanised aquaculture systems presented in the literature (and illustrate in Table 6.2).

The closed and organic feedlots rely on feeds produced on or near the system, the latter using no commercial nitrogen fertilisers, pesticides or herbicides. Rangeland beef requires no industrial energy in the provision of feeds, but requires subsidy in the process of stock management (largely fuel for vehicles), while traditional pastoralist systems require no industrial energy inputs. Although more energy efficient in fossil fuel terms, these latter systems require considerably more extensive land resources (Pimentel and Pimentel, 1979).

As noted earlier, the issue of ecosystem resources, in terms of productive land or sea area required to provide feed inputs to the system, is not of specific concern in the process of industrial energy analysis, a result of the particular systems boundaries set by the approach.

6.4 Analysis of applicability to sustainability assessment

6.4.1 Introduction

Having outlined the broader rationale for using energy as a valuation criterion, and demonstrated the application of Industrial Energy Analysis (IEA) to a range of aquaculture systems, the objective now is to consider the potential for its use in assessing sustainability. The results indicate that in terms of efficiency of conversion of industrial energy to animal protein, shellfish production is likely to be more efficient than finfish, and semi-intensive more efficient than intensive systems. Similar trends are also apparent for other livestock production, energy requirement varying with the level of intensity, and the processes involved in the provision of feeds. However, to what extent does this measure contribute to the evaluation of sustainability, and to what extent can it be used as a tool in assessment?

Intuitively, one might accept that with limited (ie non renewable) energy resources, any evaluation which helps to choose more efficient production systems would contribute to the longevity of the resource, and therefore the opportunity for that system to continue. Long term dependence on this finite stock is clearly non sustainable, although for present human society this dependence is high. This situation forms the basis for two of the operational principals for sustainable development presented in Table 2.3 earlier: the pursuit of increasing technological efficiency, and the development of renewable energy sources to substitute for reductions in stock of non renewables. In these terms, the lower the industrial energy requirement, the more sustainable a particular process should be; at the extremes of the case studies presented above, the less intensive forms of aquaculture appear to offer greater potential for sustainability than intensive. However, this criteria alone is insufficient in determining the sustainability of a particular process, as it does not account for the source of renewable resources: thus production system X may require twice the industrial energy of system Y, but draw on sustainably managed renewable resources; Y, however may be based on unsustainable exploitation of a renewable resource base. Thus these two different systems would show different comparative levels of sustainability depending on the comparative criteria applied.

Accepting that IEA does not necessarily indicate the extent to which the renewable resource inputs to a system are being exploited sustainably, in general terms it is likely that the more energy intensive systems, which by their nature represent processes which concentrate inputs from a wider resource base, are also likely to be associated with less sustainable exploitation of those resources. This concentration is also likely to be associated with potential for greater environmental impacts at the site of production, as demonstrated in the previous case study.

The discussion here considers first, an analysis of the methodology in terms of practical application, followed by an overview on the use of IEA as an evaluative indicator in its own right. The application of energy analysis set on wider systems boundaries to include renewable resources, and the role of these techniques at different levels of analysis are discussed briefly. The wider systems context for these methodologies considered in more detail later.

6.4.2 IEA: methodological analysis

The greatest problem encountered in the IEA examples above has been the choice of energy conversion values attributed to process inputs (see Annex 3, Table 1, for values and references). The choice of system boundaries and the issue of labour have already been discussed. For other inputs, the method sets boundaries at the start of the industrial processes required to sequester these goods and services. To incorporate these into the case studies, gross energy requirement (GER) of inputs were taken from published sources, from steel and plastics used to manufacture fish cages, to the fish meal required for feeds. Here the available data for each item provided a wide range of values. The main reason for this, apart from methodological differences, is the variation in effort required to obtain and process raw materials, arising from factors such as source, extraction process, distance and means of transport and processing technology.

Therefore while energy as a measure of value offers a definable and unchanging unit of measure (ie the capacity for work of a unit of energy of a specified type does not change over time: Slesser, 1974; King, 1986), the amount of work required (in terms of industrial energy subsidy) for a particular product may well change, due both to changes in the availability of the raw materials and in the efficiency of process technology[1]. Thus for the analysis of a specific process to accurately reflect the current energy costs, the costs associated with inputs to that process must reflect these changes. At present most applications of IEA rely on data generated in the 1970s: it is therefore uncertain to what extent these reflect current or future costs, suggesting that for IEA to provide an accurate measure, the values applied to the basic extractive and manufacturing industrial processes must be regularly updated.

In fish farming examples earlier, the allocation of GER to feed has been a highly critical factor, both for large scale intensive and small scale semi-intensive systems. In the former, where fish meal was a main component of the diet, the source of fish, type and abundance of stock, and fishing methods, were sources of major variation in the GER. This may well change over time, as evidenced by changes in catch per unit effort of virtually all commercial fish stocks. Similarly, agricultural practice will influence GER of products or by-products used as fish feed, as illustrated above.

Another important methodological issue concerns the allocation of energy values to by-products of other economic activities: there is undoubtedly an energy cost associated with by-product, if energy is required in the process, but should it be attributed an energy value on the same basis as the main product? In financial terms, by-products usually have zero value until someone has a use for them, when they start to assume a market value. However, this process of allocating value is usually independent of the value of the primary product[2]. In energy analysis, it is the cost of production, in energy terms, that is of interest. At the most simple level, energy cost could be attributed in terms of the marginal cost of making the byproduct available to the production process (eg transport, additional processing), although this would not reflect the true extent of dependence on energy inputs to provide that byproduct. If part of the energy cost of a

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[1] Increasing energy costs due to decreasing availability of resources (eg mining of lower grade ores as richer sources are diminished) can be expected outweigh the reductions which can be achieved through increasing efficiency, as the former can be expected to continue, while the latter is subject to diminishing returns towards a minimum thermodynamic energy requirement for given transformations (Chapman et al., 1977).

[2] In some cases choice of production method or product may be influenced by the availability of by-product, such as the decision of a farmer to grow a lower yielding variety of maize based to gain higher production of bran or stalks, which may have other, non market uses in the farming system.

production process is allocated to the byproduct (such as fish processing wastes, maize bran, or animal manures) this should reduce the energy cost attributed to the main product; this allocation could, for example, be in terms of the ratio between product and byproduct values. However, transferring an element of energy cost of production from one product to another would require analysis of integrated production systems to be carried out as a whole, rather than on a product or sector basis.

In application of IEA, there has been a tendency for crop and fisheries by-products to be allocated an energy cost in proportion to the relative weights of product and by-product. Generally animal manures are not attributed any energy cost. It would certainly appear more difficulty to justify a weight for weight allocation of energy costs to manures, given the large volumes in comparison to the main product. Alternative approaches might include a price ratio, if a market exists, or an opportunity cost related to the cost of inorganic fertilisers, if by applying manure to a fish pond additional fertiliser must be consumed to maintain crop yield. If neither of these conditions apply, then the convention of zero energy cost would appear appropriate.

To some extent the valuation of by-products is a systems boundary problem arising from the sectoral and linear approach to process evaluation discussed earlier, and represents an important methodological issues in the valuation of the resource "costs" and comparative efficiency of different production processes. These problems, however, could perhaps be seen in a different light: applying industrial energy analysis to aquaculture production systems highlights certain aspects of resource use and resource valuations, and raises new sets of questions, which could be seen as useful output from the process, rather than the GER valuation in itself. Issue such as how resources are valued in the economic system, and how production processes are viewed (as separate systems, rather than components of integrated resource use systems) represent important questions in the pursuit of sustainability.

It is also important that these methodological issues are set in context: while important in achieving accuracy in the analysis of broadly similar production systems, they are likely to be of less importance when comparing widely different technologies. For example, inputs to intensive animal production systems are generally supplied through dedicated processes, for which the energy cost can be wholly attributed[1]. Less intensive systems, on the other hand, are generally integrated more closely with locally available resources, and as demonstrate above, are likely to involve considerable lower energy costs, even allowing for valuation difficulties above.

6.4.3 The potential role of energy analysis.

The analysis has focused on the theory and practice of IEA in relation to specific boundaries of the technique. The objective here is to consider its role in a wider view of the assessment process. Some of the major criticism of energy analysis has come from economists, in reaction to the perception created by some proponents of the technique, that this represents a more appropriate long term measure of value for technology assessment. The main issues have been discussed in some detail by Webb and Pearce (1977) who question the potential contribution of energy analysis as an evaluative measure in principle, stating that it "does not have any use beyond that which is currently served by some other technique". One of the main criticisms is centred on the lack of specifiable objectives, comparisons being made to the approach taken by economics, where "the costs and benefits of particular actions cannot be defined or measured until the associated objective function has been specified operationally".

For the individual business, where market price is the focus for this objective, energetic performance is clearly only relevant where it has a bearing on the financial performance, applying, in the short term, to direct energy consumption in the form of fuel and power. As Webb and Pearce argue, these items are accounted for in pricing within the economic system. Assuming energy efficiency to be the goal of the analysis, they suggest that economic evaluation takes account of this: the price of energy is reflected as a component of the resource cost embodied in a product, "built up from all the related previous processes". The value of that resource is reflected by scarcity, and the pursuit of efficiency will automatically follow the changing availability of the resource.

Their conclusion (which although focused largely on the power generation sector was generally directed at the technique), stated that " the application of energy analysis has

[1] For example, the fish meal component of manufactured fish feeds is derived largely from industrial fisheries (Tacon, 1994).

run far ahead of the admirable motives that have produced it .... we suggest that it is a technique searching for a function".

This criticism might well appear valid if an evaluative indicator is to be proposed. The GER per kg of fish produced appears to tell little about the direct sustainability of the production process, just as the financial unit production costs derived from the model does not reveal the financial or economic viability. It is the market price, or shadow price, which allows evaluation of the latter: as long as benefits are greater than costs, the process being evaluated has the capacity to fulfil financial or economic criteria for sustainability. There is no similar rule for IEA, no clear point at which energy cost per unit production can be considered to change from sustainable to unsustainable. For GER to be meaningful in this way, a need for a better definition of the value context may be required.

However, in relation to these criticisms, Common (1977) notes that it is precisely in assuming energy analysis to be a directly evaluative indicator in its own right that the value of technique has been misunderstood. The fact that this is descriptive, rather than prescriptive should not detract from its potential value. He notes that for cost benefit analysis "to yield any relevant results it is necessary, but not sufficient, that the specification of the constraints captures the relevant stylised facts", and given that "specification is a descriptive problem.... energy analysis can offer some insights into the appropriate specification of the constraints".

What the Webb and Pearce viewpoint also overlooks is that in addition to the standard problem of utility, in terms of capital, output, resources and constraints, there is the question of ecological problems which are associated with high energy use (Georgescu-Roegen, 1975). These have been noted earlier in terms of the concentration of resources, and the consequent problems of waste generated impacts at the site of production. There is also the growing consensus on the link between energy consumption, CO_2 emissions and global warming. These features highlight the importance of perspectives such as that offered by IEA in managing sustainable development.

Given the importance of industrial energy consumption as a sustainability issue, and the increasing discussion over the potential for use of an energy tax to encourage greater efficiency, there is also an argument that this technique may have a role to play in the analysis of effects of taxation policy on commodity prices (Common, 1977). While the Webb and Pearce argument may hold true (that a change in energy costs would automatically be incorporated into product prices in proportion to the energy intensity of all economic activities involved) it does not help forecast effects of policy change. It is precisely the need to widen the systems boundaries of economic decision making process, the need for a changing world view, that is at the centre of the search for "sustainability". The following comments by Common (1977) appear to be equally applicable today:

> "What is at issue is the nature of the stylised facts which the vast majority of economists take as adequate description of the state of nature. Economics has recently discovered the finite nature of the environment within which economic activity occurs... but is not the case that many economists have got very far with working out the implications for economic analysis of that discovery. This being so, a little humility towards the efforts of others is needed".

Incorporation of industrial energy analysis into investment appraisal models

The spreadsheet models applied in this case study were developed with the intention of providing a standardised appraisal model. Thus the user could input material, operational and financial specifications, to derive GER of output, and financial performance indicators. However, the methodological problems discussed earlier limit its use as a standard tool at the project level. Where the model may contribute, however, is in illustrating the resource use implications of different systems under different sets of assumptions: applying IEA to aquaculture systems highlights certain aspects of resource use and resource valuations, raising new questions on how these resources are valued in the economic system, and how production processes are viewed. It is therefore important that the role of the model is clearly understood; not simply as a means to produce an answer, but to aid understanding of how a system might perform in uncertain and changing circumstances.

It is also apparent that the value obtained is only a very general indicator of energy cost. The degree of accuracy is such that finer differences between production processes will not tell much about that system. The results of the case study analysis suggest that a crude, but broadly representative estimate of comparative energy cost could be achieved by simply considering the level of intensity of the operation, the degree of mechanisation, and the type, means of production and source of feed inputs. At the project level, these broad criteria may be sufficient indicators.

To conclude, industrial energy analysis may be viewed as a measure of one important aspect of sustainability (non renewable resource use), but not a measure of sustainability in its own right. It may also provide a useful relative indicator of the extent to which the production system has move from an essentially renewable resource based system, and the degree of concentration of external resources (and hence ecological impact) around the location of production. It may help highlight a particular aspect of performance as a contribution to the evaluation process, complementing, not substituting, other traditional criteria and views of the system. IEA appears to be of limited value at the level of individual project assessment, although the principles of energy use in relation to broad features highlighted above may contribute to the process of comparative evaluation of technological options. Its value is likely to be greater as a tool for use at a policy and sectoral planning level.

6.5 Ecological Energy analysis for renewable resource use assessment

A limitation of industrial energy analysis as a resource use indicator is its narrow focus on non-renewable resource use (ie fossil fuel energy), which sets the system boundaries at the point of material extraction. The method does not consider the impact of extraction on the future availability of resources, nor does it value the wider resource base on which all these activities depend. As a resource use indicator, GER does not explicitly indicate the requirements for, or impacts on, rate limited renewable resources.

A systems ecology approach to energy analysis described earlier has given rise to the concept of emergy (embodied energy) proposed by Odum (1988). Measured in solar energy equivalents, this represents all the processes and energy transformations involving renewable and non renewable resources embodied in a product. This can be applied in the analysis of efficiency of production (ie emergy cost of production, as for IEA) for individual processes, or whole economies.

Between the extremes of emergy analysis and IEA, there are intermediate approaches. For example, an analysis of the efficiency of conversion of incident solar radiation to useful products has been used to study integrated aquaculture farming systems (Ruddle and Zhong, 1988); this particular study does not, however, consider the energy of the hydrological and atmospheric contributions to the production system. Applied to intensive fish farming, Folke (1988) has estimated the total (biological) energy content of fisheries and agricultural products used in producing farmed salmon, again in terms of solar energy harnessed by primary producers. Similar analyses have been made for a range of livestock species and production systems by Pimentel and Pimentel (1979).

While conceptually these approaches also have the limitations with respect to value objectives, they can, as with IEA, deal with the wider evaluation of the contribution of environmental goods and services to human activities. However, there are methodological problems in deriving meaningful and comparable results: the process of conducting a full biophysical analysis of a production system in a particular context remains beyond the realms of most project related activities. However, as in the case of IEA, knowledge of the energy characteristics of different systems can provide the basis for broad assessments about their comparative efficiency. This is principally related to the source of food (and means of production), and the feeding habits of the species concerned: the lower in the food chain, the more biomass produced from available solar energy.

In this context, one of the advantages of fish culture over terrestrial livestock production is the greater efficiency in the transformation of feed (see Table 6.3). This is largely due to variations in the energy required for activity and maintenance of body function. As fish are poikilotherms, they do not expend energy maintaining a constant body temperature. Less energy is also required for activity due to the support provided by the aquatic environment (ie fish generally maintain neutral buoyancy). Even lower energy expenditure is required for shellfish, which, unlike the foraging terrestrial and other aquatic herbivores, remain static, food being transported to the point of consumption by water currents. However, this does not mean that fish can or should necessarily replace terrestrial production systems, or that fish farming should only involve herbivorous species: such propositions are clearly over-simplistic. The specific resources and opportunities available, amongst a range of other factors, will influence the choice of technology and the products involved.

Table 6.3 Comparative efficiency of food conversion in livestock*

	Fish	Poultry	Beef
1g dry food to live weight	0.84g	0.48g	0.13g
1g dietary protein to body protein	0.36g	0.33g	0.15g
1000kcal dietary energy to body protein	47g	23g	6g

*this does not consider type or quality (in embodied energy terms) of feeds.
(Source: Jauncey, 1994)

While beef production may be significantly less efficient in food conversion than other herbivores, they can use plant materials which might have limited other uses, grown on land unsuitable for agricultural cultivation. Intensive fish production, in specific circumstances, may offer opportunities for the conversion of fisheries byproducts unsuitable for human consumption into high value foods.

6.6 Energy analysis at the macro-economic level

This thesis is primarily concerned with the problem of sustainability analysis at the project or activity level. However, as suggested in Chapter 2, the sustainability of individual activities must be set in the context of the sustainability of the whole. It is therefore of interest to consider how energy analysis, which may be limited in routine application at the project level, might be used as a numeraire in macro-economic models.

There are two main approaches to this, which represents the two different but related levels of energy analysis discussed earlier. These are the natural capital accounting model, ECCO, developed by Slesser et al. (1994) and the Emergy models developed by Odum (1988). The ECCO model is an attempt to develop "natural capital accounting procedures for managing sustainable development" by the development of non-monetary indicators against which the potential outcome of different policy options can be tested. The emergy modelling approach at the macro-economic level has been proposed by Odum (1988) as a measure of work done at all levels in the system. He suggests that the relationship between money flows and emergy in and between economies (in emergy units), can provide a measure of the true resource costs of human activities and exchanges, at present not reflected in the market economy. He illustrates this by demonstrating that products of rural economies (developing countries) have a much higher emergy content per $ received from trade than those of developed economies. This represents a net transfer of (ecosystem, or emergy) value from rural to urban economies: the result of such unequal trade being resource depletion in developing countries. Odum therefore proposes that by relating economic indicators with emergy measures (in natural and man made systems) for whole economies, a currency/ emergy ratio can be derived on which fairer trade, based on equal emergy transfer, could be based. There is clearly a wide gap between this theoretical analysis and the present basis on which trading relationships are established.

6.7 Summary and Conclusion

The objectives of this chapter were firstly, to investigate the potential for energy analysis, focusing primarily on industrial energy analysis (IEA), to provide an indicator of sustainability of production activities. Secondly, to investigate the potential for the IEA spreadsheet model which provided the basis for this case study analysis of aquaculture systems, to be used more widely as an evaluative tool. The application of wider system boundaries for energy analysis was briefly discussed. The main points arising from the analysis of case studies and the literature are as follows:

- The issue of non renewable and renewable resource use efficiency is of major importance to the question of sustainability. Energy as numeraire provides a means of quantitative assessment for various aspects of resource use, depending on the choice of system boundaries.

- As a descriptive rather than objective related indicator, energy cost can not be set against an absolute value by which the sustainability of production processes can be assessed. However, energy assessment methods can be used to measure the extent to which alternative options move towards efficiency goals implied by sustainability, and therefore represent potentially useful tools for sustainability assessment.

- Methodological problems in valuing energy costs of inputs limit the accuracy of individual analyses in IEA. Such valuation problems are compounded in ecological energy analysis in terms of data availability and reliability, due to the complexities of the systems involved.

- The value of these techniques, however, can be seen in terms of providing an understanding of efficiency characteristics of different types of production systems and processes, and a broad comparative measure.

- The potential of these approaches is likely to be of more significance at a macro-economic level than at the project level, as it is likely that increasing efficiency can only be achieved by suitable policy level measures, such as taxes, or efficiency incentives.

Chapter 7

Case study 3

Sustainability at the development level: aquaculture in rural communities.

Chapter 7 Sustainability at the development level: aquaculture in rural communities.

7.1 Introduction

Aquaculture tends to be located in rural areas, due to the physical requirements of the production system. Although a small component in the natural resources sector in general, it can be important in specific locations. Aquaculture associated with rural support or development, in developed and underdeveloped economies, range from intensive commercial operations, to extensive and subsistence level activities. The stated objectives of aquaculture development are generally within the frame of national and rural economic development, and more typically in less developed countries (LDCs), food security (see Chapter 1). The value criteria applied in assessing the viability of these projects are generally based on the financial return to the investor, and to varying degrees the wider economic benefits to the local community, usually evaluated on the basis of accepted economic indicators (Wijkstrom, 1991; UNIDO, 1978).

The weakness of such indicators in terms of environmental and resource use sustainability have been noted. However, the previous case studies have not considered these methods in terms of the social aspects of sustainable development in rural communities. Nor have they considered how aquaculture development might fit into other practices and activities in these communities, what integration or competition there might be, and how measures of "success" and "sustainability" might be influenced by the value criteria applied by those involved in the development process: ie the cultural capital component of the sustainability spectrum.

This chapter examines these issues using a case study based on an economic appraisal of a rural smallholder aquaculture development project in southern Africa. This is a conventional development project involving a range of participants, including donor and recipient governments, their agents and officials, local institutions, communities, families and farmers. The focus is on two central themes, the project process itself, and the methodologies applied in that process. In the project process, developments are identified, appraised and implemented. This process itself is a product of the roles and perceptions of the stakeholders involved, from the donors to farmers. To some extent this case can be seen as a "typical" interface between the values and views of the peoples of developed industrial economies and subsistence based, "underdeveloped" economies. Within this process there are accepted and required methodologies which are set in the context of the 'project cycle' (FAO, 1991)[1].

The theme here concerns how well this process, and the methodologies applied, both during the initial appraisal and implementation, provides a mechanism for identifying and supporting sustainability. The particular context examined in this case is that of the individual and societal aspects of sustainability, in terms of uptake, participation, local and wider economic benefits, and general social benefits. Resource and environmental sustainability are clearly equally important, but are not a particular focus here. These themes are examined as follows:

- the case study, based on a semi-subsistence level aquaculture project in Southern Malawi, follows the project through from the initial appraisal to a post-hoc analysis. The methodological issues apparent at the time of the appraisal, and those which became apparent during project implementation and mid-term evaluation, are discussed. The initial fieldwork for the case was carried out in 1986, and was based on the specific requirements of the terms of reference provided[2].

- the issues of sustainability raised by this case are discussed further in the context of similar development activities and research projects in the region, including fieldwork for more recent projects in Central and Northern Malawi and NE Zambia, which have had specific sustainability objectives.

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[1] The terminology used here for different stages in the project process is as follows: the appraisal represents the detailed assessment of the technical, financial and economic viability of a proposed development (at this stage outline objectives and means have already been identified). Evaluation reviews the performance of the project, sometimes during, but usually after implementation.

[2] this case must be seen in historical context: many of the issues illustrated here by their absence are now more widely recognised in rural development approaches. In particular, the TOR for the appraisal did not explicitly include social or environmental aspects. Nor did it require the preparation of a project framework, in which objectives, indicators and mean of assessments, and assumptions and risks, are identified.

7.2 Case Study 3: Small scale aquaculture development in southern Malawi

7.2.1 Background

The fieldwork was carried out as part of an ODA (Overseas Development Administration of the UK) initiative to assist the Government of Malawi (GoM) in the support of smallholder aquaculture development. The specific objective was to "assess the viability of a proposed smallholder fish farming development project in the Mulanje and Phalombe districts"of Southern Malawi. Details of the appraisal mission itself are given in Beveridge and Stewart (1986).

The rationale for the project was set in the context of the importance of fish as a source of animal protein for the people of Malawi. The capture fisheries from Lake Malawi, representing the major source of fish, were reputed to have peaked at about 75,000 tpa in the mid 1970s, fluctuating from 60,000 to 70,000 tpa into the mid 1980s, when this project process was initiated. With a growing population, this per capita consumption was seen as inevitably falling. Furthermore, due to distribution problems, more distant communities had more limited access to this resource.

At the time, smallholder aquaculture, in some cases integrated with livestock and other agricultural activities, was seen as a simple, low cost and achievable means to improve the access of rural agricultural communities in the wet tropics to low cost fresh fish. This was also popularly viewed as an alternative means of alleviating the shortfall in fish production from mismanaged natural fisheries, both in regions of traditional aquaculture, and, as in this case, in those with no real history of aquaculture.

The Department of Fisheries (DoF) in Malawi was already involved in rural aquaculture development, with a research station and extension service in Central region. An aquaculture development project in the Northern region was in the process of being approved for funding (by the EEC; Landell Mills, 1983), while in the south, a NGO project at Mwanza had supported significant development of smallholder fishponds in the early 1980s. In this case the project proposal was based on the perception of great local interest in fish farming, and the inability of existing DoF resources to provide the required support, either in terms of stock or technical advice. The initial request for technical assistance was made by the DoF to the British Development Division of Southern Africa (BDDSA) in Lilongwe. At the time there was a full time British counterpart to the Director of Fisheries, and a long history of technical assistance from the ODA.

This resulted in the appraisal mission on which this case is based, representing the first significant commitment of resources by the ODA to the potential project. The terms of reference gave clear guidelines for the structure and function of the proposed development. This was to consist of a central hatchery and fingerling production facility; a demonstration farm, with extensive fish culture in small ponds integrated with livestock production, and an infrastructure for the distribution of fingerlings and training of farmers. A broader description of the proposed activities at the farmer and project level is presented in the project appraisal document (Beveridge and Stewart, 1986).

7.2.2 Methodologies

The approach to the financial and economic appraisal involved the application of standard methodologies to model fish farm operations and proposed project activities. The details for the former are presented below, and the approach to the latter is summarised in the presentation of results. The models developed were used to assess the potential viability of aquaculture activities, and at a macro-scale, the potential relationship between development 'gain' - in overall production, income and economic value- and project costs.

Information for the proposal was obtained from government departments, development workers, farmers and local market studies. Official statistics included demographics, geological and climatic data, agricultural statistics (holding sizes, crops types and areas, livestock ownership etc) and fisheries statistics (yields, trends, market networks and values, aquaculture data). Model fish farmer case studies were based on information from existing smallholder fish farmers, Government research stations and overseas sources. Smallholder based fish farming models were developed based on 0.05 and 0.1ha ponds: in practice a very wide range were likely, depending on availability of land and labour, in addition to the level of interest of the farmers. The larger pond model assumes an integration with poultry production developments (proposed by the regional Agricultural Development Division, BLADD, 1986). The assumptions used are outlined below, summarised in Table 7.1.

Capital items

Land: it is assumed that the land used for the fish pond was suitable for agricultural production, the lost benefits of which were attributed as an opportunity cost of fish production. This was primarily due to the significant pressure on land in the region[1].

Construction: the labour requirement for construction of the pond was based on the volume of earth moved per person per day (generally a male activity). The model was evaluated for both extremes of a full market value for labour, and a zero opportunity cost of labour. The latter was justified on the grounds of seasonal labour surpluses during the dry season (BLADD, 1985). A minor allowance was made for the hire of equipment for pond construction (which the DoF proposed supplying).

Operating items

Labour: this was not included in the evaluation. Information available suggested that labour required for management of the fish pond was less than that required for the management of the displaced crop (assumed due to the shortage of land). Given the difficulty of assessing the actual input and value of family labour used for crops or fish farming, the model aims to assess the potential marginal benefits of changing from one activity to another, in terms of return to land and labour. By assuming equal labour requirement, the suggested lower labour requirement of pond operation represents a degree of conservatism.

Feeds and Fertilisers: it was assumed that one feed and one fertiliser was available. In practice, a wide range of plant materials and other organic byproducts could be used to improve pond productivity and fish growth, either directly as feed or indirectly as fertiliser. The quantity of resources available was estimated from agricultural statistics for

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[1] In practice, ponds could be constructed on marginal land with no agricultural use. However, such land may also contribute goods and services to subsistence livelihoods, therefore some valuation may still be justified.

the region, concentrating on the principal crop by-product (maize bran) and the principal livestock byproduct (chicken manure) based on average holding statistics.

Output assumptions

A yield estimate was based on what could easily be achieved given a reasonable level of management and the calculated available inputs. A market price of 60% of the local market value was assumed for the output, given that, if sold at all, a lower price might be achieved at pond side sales. This was therefore a conservative estimate of the potential benefits. In practice, much of the produce could be consumed by family and relatives, or bartered for other goods or services.

Where possible, a notional financial value was attributed to all inputs and outputs, although in most cases these would not be part of the market economy.

Table 7.1 Cost and revenue assumptions for smallholder case studies

Capital Inputs and Costs (MK, Malawi Kwatcha)		
Pond construction: hired labour Water supply and drainage Equipment hire		$0.25/m^2$ surface MK 5.0 MK 5.0 per $500m^2$ pond
Operating inputs and costs	Quantity	Cost (MK)
Manure Madea (maize bran) Stock Tilapia Carp Additional poultry for 0.1ha model: 14 day old chicks Home made poultry feed	1.5t/ha 6.5t/ha $1/m^2$ $1/5m^2$ 8 60 kg/bird	0.03/kg 0.05/kg 0 0.05 each 1.18 each 0.16/kg
Outputs and Revenues	Yields	Market Value (MK)
Fish: Tilapia Carp Poultry: Spent layers Eggs	1300kg/ha 400kg/ha 8/year 12 doz/bird	1.0/kg 1.30/kg 2.40 each 1.35/Doz
Opportunity costs of land	Location	Average Crop Value (MK)
Average (net) value of lost crop (BLADD 1985)	Mulanje West Mulanje South Phalombe	261/ha 310/ha 205/ha

7.3 Results of the appraisal process

7.3.1 Introduction

The results of the initial appraisal mission and subsequent stages of the project are considered below as follows:

- the assessment of smallholder farming systems and the proposed project are summarised, based on the appraisal mission report (Beveridge and Stewart, 1986).

- the outcome of the appraisal mission is discussed in terms of project implementation, the findings of a mid term project review, and subsequent project details based on information obtained on a further mission to Malawi in 1993.

7.3.2 Conclusions from model fish farming operations

The benefits of fish culture (in returns to land and labour) are presented net of the lost crop returns. The incremental benefits are also presented as payback on capital costs, although again this is a notional value where family labour is used. The model fish farming operations are presented in Tables 7.2 and 7.3. At the individual farmer level, the analysis suggested that the proposed fish farming options tested would bring considerably higher operating returns than the principal crop, maize, even if fish were sold at well below the current market price. Considering that most of the costs of inputs are notional values, these returns are therefore conservative. When full capital costs are assumed for pond construction, the returns are less attractive, with payback of about 5 years in the base case. This suggests that the fish pond may not be a particularly attractive investment of cash resources, although the return improves with changes in the assumed opportunity value of inputs, and less conservative market price assumptions. In many cases on farm labour may be used during the dry season, in which case there would be minimal or no cash costs for pond construction.

Table 7.2 Model 0.05ha Smallholder fish farm

(Tilapia monoculture and tilapia carp polyculture)

PHYSICAL SPECIFICATIONS				
Pond type	Breeding		Production	
Pond area	100m^2		400m^2	
Fish yields (kg/m^2/yr): Tilapia	0.065		0.13	
Carp	0		0.04	
TOTAL CAPITAL COST	MK 135			
OPERATING INPUTS AND COSTS	Tilapia only		Additional costs with tilapia and carp system	
Item	Quantity	Value (MK)	Quantity	Value (MK)
Madea (kg)	325	16.25		
Manure (kg)	75	2.25		
Stock Tilapia (kg)	10	0		
Carp(no.)	0	0	160	8.00
Net hire		4		
TOTAL OPERATING COST		22.50		30.50
OUTPUTS AND REVENUES				
Tilapia (kg) @ MK 1.0/kg	58.5	58.50		
Carp (kg) @ MK 1.3/kg	0	0	16.0	20.8
TOTAL REVENUE		58.50		79.30
RETURNS (to land, labour, captial)				
Net Return		36.00		48.80
Value of lost crop		15.4		15.40
Net return as % lost crop		234%		317%
Net marginal benefit		20.60		33.40
Payback (on full capital costs)		6.5 yrs		5.5 yrs
SENSITIVITY ANALYSIS	Margin (MK)	Payback (Years)	Margin (MK)	Payback (years)
Sales @ full market price (MK 1.7 and 2.0 /kg for tilapia and carp respectively	61.5	2.3	85.5	1.6
+Opportunity costs Manure and madea =0	80.0	1.7	104	1.3

Adapted from analysis in project document (Beveridge and Stewart, 1986)

Table 7.3 Model 0.01 ha Smallholder fish farm

(Tilapia carp polyculture integrated with poultry)

PHYSICAL SPECIFICATIONS		
Pond type	Breeding	Production
Pond area and number	200m² *1	400m² *2
Fish yields ($kg/m^2/yr$) Tilapia	0.065	0.13
Carp	0	0.04
TOTAL CAPITAL COST (ponds and poultry coops) MK 273		
OPERATING INPUTS AND COSTS		
Item	Quantity	Value (MK)
Madea (kg)	650	16.25
Manure (kg)	150	2.25
Stock Tilapia (kg)	20	0
Carp (no.)	320	0
Net hire		4
	Sub total fish	22.50
Extra poultry production		
Chicks	8	14.4
Feed (Kg/bird)	60	76.8
	Sub total poultry	91.2
TOTAL OPERATING COST		145.95
OUTPUTS AND REVENUES		
Tilapia (kg) @ MK 1.0/kg	117	117
Carp (kg) @ MK 1.3/kg	32	41.6
	Sub total fish	158.60
Spent layers		
Eggs (doz)	8	19.2
	96	129.6
	Sub total poultry	148.8
TOTAL REVENUE		307.4
RETURNS (land, labour and capital)		
Net Return		161.45
Value of lost crop		30.28
Net marginal benefit		131
Payback (on full capital costs)		2.0 yrs

Adapted from analysis in project document (Beveridge and Stewart, 1986)

The integration of larger fish ponds and poultry production also appears to generate significantly greater returns than the principal crop. However, while the costs associated with the fish pond operation are largely notional opportunity costs, those incurred in the proposed poultry unit are more likely to be cash investments. It is therefore clear that within the integrated operation the risks associated with the poultry production are considerably greater than for the fish pond component. The viability of fish culture in this case is therefore secondary to that for poultry. If the latter was viable, then the former might represent a profitable source of integration.

The conclusion reached was that fish farming could represent a worthwhile additional activity for smallholder fish farmers, even when replacing a proportion of existing crops, particularly when on farm resources are used. Where negligible or zero opportunity costs for land and/or labour were involved, the attraction of fish farming would be considerably greater, and if poultry production were profitable, fish farming would be an attractive complementary activity.

7.3.3 Summary of the project appraisal

At a project level, a broad estimate of the likely uptake of this technology was made from purely physical characteristics of the landscape and soil type. The total annual yield which might be achieved from smallholder production by the end of a 4 year development project was estimated at between 10 and 25 t/yr. This was based on the successful adoption of aquaculture by 300- 600 farmers. The appraisal was also extended to include an assessment of the potential for increased regional fish production from estate ponds and reservoirs, which accounted for an estimated additional 30 to 75 t/yr by the end of the project (Table 7.4). A market survey of fishery products in the region suggested a total annual market of about 1400 tonnes, and a per-capita consumption of about 3.7 kg per year, 40% of the national average. The project would therefore not be expected to have any significant impact on prices or demand.

Table 7.4 Predicted potential for aquaculture development

Sector		Worst case	Best case*
Smallholder sector:	Number	300	600
	Pond area	7.75 ha	15.7 ha
	Total Yield	10.06 t	25.9 t
Estate Ponds:	Number	25	40
	Area	5 ha	8 ha
	Total Yield	7.0 t	13.6 t
Estate Dams:	Number	4	4
	Area	16	16
	Total Yield	20.8	26.4
Grand Total (tonnes / yr)		38	99

*Best and worst cases include changes in yield assumptions.

Adapted from project document (Beveridge and Stewart, 1986)

The institutional infrastructure required to achieve this development was broadly specified in the appraisal mission background material, based on similar developments elsewhere in the country. Station facilities specified included buildings (office, staff housing related to government specifications, livestock housing, stores), fish production systems (broodstock, fry production, and demonstration ponds integrated with livestock). The support to farmers was to be through the activities of extension workers, using motor cycles or bicycles, supported by the station vehicle (4WD) for delivery of fry and other assistance. During the initial implementation of the project, technical assistance in the form of a counterpart project manager was proposed. The costs of implementation were based on local and offshore prices available at the time; a summary of main inputs and costs for the project and estimated ongoing running costs is shown in Table 7.5, which represents the base case conditions. It was assumed that all donor funding would continue to the end of year 4, but that the GoM would cover local staff costs during this period, and on-going costs following project completion.

The financial analysis of the project in the base case, representing the overall objective of the appraisal mission, considered NPV and IRR for upper, lower and medium output assumptions at current market values (Table 7.6). The analysis also demonstrated the notional value of additional fish required to achieve an IRR of 10% at different outputs.

Table 7.5 Summary of base case project costs (Mk)

ITEM	inflationary adjustment	1987/88 0	1	Year 2	3	4	5+
CAPITAL COSTS							
Site preparation	(+10%)	15400					
Buildings	(+15%)	248975					
Other construction	(+15%)	27888					
Services to site	(+15%)	32430					
Motorised vehicles	(+20%)	34200					
Other plant	(+10%)	13255					
		372148					
Physical contingency +5%		18607					
TOTAL CAPITAL		390755					
ANNUAL COSTS*							
Salaries and wages		45596	92656	92656	15232	15232	15232
Maintenance and running		16394	28853	28853	19203	29203	29203
Training and research		500	21456	1800	3256	1300	0
Livestock, Agricultural		6560	7960	7960	7960	7960	7960
Total expenditure		69149	150925	131269	56651	53695	52395
less Revenues from livestock etc.		0	10045	12182	13482	13670	16070
TOTAL ANNUAL COSTS		69149	140879	119087	42169	40025	36325
TOTAL COSTS		459904	140879	119087	42169	40025	36325

*Note: the inclusion of annual costs in year 0 is based on the assumption that the station will staffed and start operating while capital developments are in progress.

Table 7.6 Summary of Cost-Benefit analysis for the base case project

Costs (MK)		**Development phase (years 0-4)**	**Year 5+** (from Table 7.5)
	Capital	390755	
	Operating	411309	36325
TOTAL		802064	36325

NPV and IRR for varying yields[1]

Annual Yield (tonnes)	NPV[2]	IRR	Market price required for IRR of 10% (MK/kg)
40	-557	<0%	4.7
70	-337	<0%	2.7
100	-117	6%	2.0

Notes: [1] Rate of uptake (and yield) assumed to be 15%, 35%, 75%, and 100% years 1-4 respectively
[2] NPV in MK *1000 at discount rate of 10%; Market price 1.7 MK/kg

The results of the analysis of the base case suggested that the project was not viable, giving an IRR less than zero for lower and medium output estimates. Even in the best yield scenario, the IRR achieved was only 6%. The economic value attributed to the project generated fish production would have to be about 60% above the estimated market value to achieve an IRR of 10% at the mid-range output.

The poor performance of the potential project in economic terms was primarily due to the high capital costs of providing the central project station, and its high operating costs in the initial years, largely due to the employment of an overseas expert - ODA Technical Cooperation Officer (TCO) - as a counterpart to the project manager. To investigate means of improving this performance, the effect of a range of different cost reduction measures were demonstrated (summarised in Table 7.7): these included changes in the design and structure of the project facilities (primarily achieved through lower grade staff housing), and changes in staffing arrangements (replacement of the TCO level project manager by a volunteer through the UK Voluntary Service Overseas, VSO[1]). The potential risk of these changes having an impact on project achievements, in particular the option of employing a volunteer rather than a more experienced project manager, were highlighted in the appraisal document.

Table 7.7 Summary of cost benefit analysis of alternative project options

Development phase costs MK (to year 4)	Base Case	Option 1 Capital reduced[1]	Option 2 Operating reduced[2] (VSO replace TCO)	Option 3 Both 1 and 2
Capital	390755	268798	330380	245223
Operating	411309	387212	210309	214212
TOTAL	802064	666010	540689	495435
IRR @ output				
40 tpa	<0%	<0%	<0%	<0%
70 tpa	<0%	2%	6%	11%
100 tpa	6%	12%	16%	22%

Notes: [1] Mainly achieved through reductions in building costs (40% down), which were for standard government staff related specifications in the base case. This also reduces operating costs due to reduced maintenance assumptions
[2] Employing a VSO also allows reduction expatriate housing specifications in capital

[1]in effect transferring the ODA overheads from the project to another reduced "aid" budget.

7.3.4 The post-appraisal outcome

There was a clear demand the institutional level for a project in this sector, and at least at an informal level, this was potentially one of the more promising options, having been through the first stages of project development carried out by Malawi government staff and in-country donor representatives prior to the appraisal mission. Although there were general development criteria to be met, these were treated relatively flexibly by the institutions concerned, to allow the project the 'benefit of the doubt'. The proposed project was approved for funding by the ODA in the form of an amended base case design, incorporating reductions in housing and staffing costs illustrated in Table 7.7. It was also reported that donor and DoF staff considered that the true value for additional fish production had been underestimated in the appraisal, thus further improving the apparent viability of the project (Mutambo, 1991). As a relatively small project, the decision to fund the development was made by the in-country donor representative[1].

The implementation of the project officially started in October 1987, although due to technical and staffing problems, it was not fully operational until early 1991. These delays meant that the post-implementation evaluation of the project, planned for and carried out in 1991 (Hyde, 1992), in effect served as an interim review. The points of interest in the evaluation of the project process are:

- firstly, the extent to which the project had achieved the objectives set out in the appraisal document, and how closely the models and forecasts of potential reflected what actually occurred.

- secondly, with the benefit of hindsight, the review mission's view on the appraisal report is discussed.

These issues are considered below, first in terms of institutional and infrastructure development, and second, in terms of fish farm developments arising from project

[1]At this time there appeared to be no formal requirement for preparation of a project framework, in which objectives and implementation plans must be clearly stated against indicators, means of assessment, potential risks and assumptions. The explicit objectives considered in the project appraisal document were to increase fish production, with an implicit assumption (describe in general terms) that economic and nutritional benefits would follow.

activities. Information presented is developed primarily from the report by Hyde (1992), with additional information from the initial appraisal field work, and later communications with DoF staff.

Institutional aspects of implementation

The technical and management problems which delayed implementation of the project were reported to also have limited its ability to fulfil its objectives once operational. Firstly, the construction phase lasted for over two years, when the project document suggested that this should take 4 months: this was associated with a range of factors, including site selection, changes in project design specifications, and administrative delays in financial disbursements through the DoF head office in Lilongwe, which led to problems with local suppliers of building material. Secondly, problems with water supply systems for ponds, and leakage due to poor soil conditions (implying poor site selection) caused delays and limited the ability of the project to supply fry to farmers[1].

Third, there were considerable staffing problems, for both local and expatriate staff. The review report suggests that "the external technical input as envisaged by the original project design was negligible, as the construction was still in progress when he (the volunteer) was in charge". Local staffing problems included a serious shortfall in technical staffing (only 4 of the recommended 15 technical and advisory staff were appointed). Among those staff, the need for better technical training was highlighted by the review as a principal constraint to fulfilling the project's objectives.

Finally, additional problems associated with transport (lack of fuel and other funds) and a project area which was expanded from the original project design (authorised by the DoF) limited the activities of the extension services: the review report states that "it is clear that the station has neither the manpower nor the resources to physically cover the territory it has assigned itself"

[1]the initial appraisal made suggestions for potential sites and outlined required selection procedures, although a full site evaluation was beyond the scope of the study.

Aquaculture activity and associated benefits

The review states that "the project has made a definite difference in the rate at which fish farming is being adopted". In one of the three project regions, the number of farmers had increased from 64 in 1987 to 149 at the time of the evaluation, which the evaluators considered to be encouraging, given the above problems[1]. However, there was a significant discrepancy between project objectives and review findings in terms of the level of fish production generated by the project, and the benefits of that production. The review states that "the total tonnage harvested for 1990/91 .... was 1.05 tonnes: the five year target was 40 -100 tonnes per annum; there is some way to go yet" (ie 1 - 2.5% of the quoted target). The discrepancy is, at first sight, vast. However, the forecast production from the smallholder sector was actually 10 - 25 tpa, as the balance was to come from small water bodies, mainly estate ponds (Table 7.4). The recorded yield therefore represented 4% - 10% of the quoted target for that sector. There appeared to have been no efforts to support development of estate based production, although this was a reported target of the DoF. The fact that the project had only been in effective operation for 1.5 years, and the limitations of technical facilities and staffing may partially explain this low yield, but the shortfall is still considerable.

On an individual farmer basis, data available suggests that the average yield was about 20% of the production assumed in the model operations. Therefore although these models were considered to be conservative in terms of yield estimates they were, in hindsight, clearly over optimistic[2]. The stated project objectives of improving the nutritional and socio-economic status of the smallholders of Mulanje/Phalombe attracted particular comment. The review concluded that the introduction of fish ponds made no real difference to the availability of fresh fish in villages. This comment, however, was qualified in view of the problems of collecting production data: as the DoF insisted that

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[1] no figures were provided for developments in the other two regions

[2] Yields for tilapia monoculture integrated with other livestock and farming activities vary widely, depending on the resource inputs available. The yield assumed in smallholder farmer models above was 1.3 tn/ha/yr, based on DoF data. Published sources for tilapia species in integrated systems report yields often in the region of 2- 3 tn/ ha/yr (see Pullin and Shehadeh, 1980; Little and Muir, 1987) to as much as 10tn/ha/yr (Thailand, Little, 1987, pers comm.), although these systems are heavily dependent on high levels on manure inputs from associated livestock production.

all harvesting should be carried out in their presence, the farmers may have been reluctant to impart information on "unofficial" harvests. Generally, farmers were considered to be reluctant to divulge financial information[1]. Accepting the problems with data collection, however, the review was still critical of the project in respect of expected farmer and community benefits, commenting that "the links between the establishment of fish ponds and nutritional and socio-economic status were not clear at the start of the project and still are not clear".

As this was considered as a mid-term review, the project could not be finally judged in terms of success or failure. However, it is clear that in terms of fish production it was falling well behind its forecast impact. On the other hand, in terms of the number of farmers taking up fish farming, the impact was in line with the project proposal forecasts. The community level effects remained unclear.

The review team were generally supportive of continued project activity, given the previous problems in implementation, and in spite of the lack of clear links between the project activity and the wider economic and social benefits. The recommendations included the need to increase staffing levels to those specified in the project proposal, and a number of changes to the ongoing management of the project. The external donor, however, did not take the same view, and further financial support to a second phase of the project was not approved. Unofficially, this was reported to have been associated with the donor's lack of confidence in the ability of the host government to provide the required resources and management, and in particular with the continued presence of the local project manager.

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[1] This raises questions as to the extent to which the short term review mission was constrained by the same problems as the initial appraisal mission: limited time and the lack of reliable data. The review did not consider a number of potentially important aspects such as the attitudes of farmers; are they happy with their ponds? do they feel they are getting the expected benefits ? If not, is this based on unrealistic expectations from the level of inputs and effort they can afford to, or wish to invest- ie is it a problem of over-optimistic expectations, or a lack of knowledge due to institutional failings in project implementation (or project design, in terms of the extension effect expected/ achieved?).

As a final stage in the case study, and to assess the continuing operation of the project, the project station was visited in October 1993. A small staff continued to offer extension advice to a number of local farmers. They reported problems of under staffing, lack of transport and money for fuel. Most of the station ponds were empty due to the recent drought, leading to an inability to supply farmers with requested stocks. Drought was also reported to be a problem for many of the farmers who had constructed fish ponds. The project manager was not present, and the staff present were unable to provide any statistics in terms of current status and performance of aquaculture in the area.

7.4 A post-hoc analysis of the project process

7.4.1 Introduction

It is clear that the project failed to meet the expected results of the approved project design, in both its performance as a whole, and at the level of individual fish farming operations. To what extent can this be attributed to the project concept, the project function (and poor management), or the project process? In particular, what is the role of the appraisal methodology in this process, and can lessons be derived from this sequence of events to improve the development process?

The appraisal outlined above was based on the development of technical and economic models of both fish farm and project level activities. These are, by definition, simplifications of reality, but represent an approach widely used in the project identification and appraisal stage of such developments. In view of the underlying objective of the development process, which sets out to provide a foundation from which activity will continue to spread and develop after the project intervention, the analysis should serve as a predictive indicator of sustainability, however crude, in social and economic, if not environmental, terms. To what extent does the appraisal achieve this goal?

- at a farmer level, how accurate are production models in reflecting the range and scale of activities actually developed, and can such models provide an indication of the sustainability of the technology in the specific environment?

- at the project level, to what extent can the short term appraisal mission identify the potential scale of development, and the potential for wider benefits in terms of nutrition, food security and local economic growth?

- in broad terms, to what extent does this approach to rural development provide a mechanism for identifying and supporting sustainable activities? Do donor driven approaches correspond with those understood and supportable within the local context?

- in relation to these points, what is the role of the appraisal team, and do their preconceptions and interactions distort the effectiveness of the appraisal?

The objective here is to consider the methodological problems involved in the project process. These are analyses in terms of the project concept, which resulted in the specification of the terms of reference and selection of the consultants for the project appraisal mission. The issues are considered further in the context of more recent research on the socio-economic aspects of rural aquaculture development in the region. The criteria or indicators for assessing the sustainability of aquaculture development in semi-subsistence rural economies in general are discussed.

7.4.2 Assessing farm level potential

During the appraisal process, a number of constraints to the development of production models of existing and potential fish farming activities were encountered. The appraisal mission involved visits to a number of small scale fish farmers, arranged by local agriculture extension workers. The objectives were, first, to obtain data for the technical and economic analysis of fish culture currently practised, and second, to identify the potential of such systems given improved assistance to farmers. The focus was on what was, and could, be technically achieved, and what economic benefits might be expected.

At the most basic level, it is relatively simple to assess whether fish farming is physically feasible (are soil conditions suitable, are water and other inputs available?), and if there is likely to be a demand for the output (do people like fish, eat fish, buy fish, and what other competing fish and animal products are available?). The problems of making a more accurate technical assessment are primarily due to the lack of data on the resource availability and flows in both existing and potential fish farming systems. However, given that some information was available on the resources for potential use in pond production, broad assumptions about potential yield were made. Although conservative yield estimates were applied, it appears that these models were still over optimistic. Quantifying the 'yield gap' between research station and on-farm trials, and results likely to be achieved on a wider basis in the rural farming community, is clearly a critical factor in this modelling process[1].

For financial/ economic analysis, the problems of lack of quantification were compounded by the problem of valuation. In many cases, the activities of small scale farmers are only partially tied into the market economy. Many of the resources used in fish farming may not have a market value, although in some cases there may be alternative productive uses of these resources. This includes land and operating inputs. While the concept of opportunity cost can be used to attribute a notional value to these resources, the problem of how to value that opportunity remains.

While the models presented in this case indicated that fish farming could be a worthwhile new activity for individual farmers, the degree of uncertainty in the quantification and valuation highlights the limitations of such approaches in reflecting "the real world" of the smallholder farmer. This does not mean that these models are not useful tools, but that their use must be set in the context of their limitations.

7.4.3 Assessing project level potential

The principal task in this respect is to make an analysis of the total costs and potential benefits of the proposed project. While making an estimate of the costs of providing the infrastructure and staff is relatively straightforward, the potential benefits are

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[1] The problem of the 'yield gap' in agricultural production has been attributed to the marginal nature of many resource poor farming operations in comparison to research facilities, which are often located on better quality land, and do not represent 'stress' situations (Maurya, 1989). Furthermore, the knowledge required for the management of new varieties or production technologies is often lacking, or the priorities set by farmers conflict with output maximisation, resulting in lower productivity, even where extension services are set up to deliver 'appropriate' training.

considerably more difficult to assess. Forecasting the uptake of the new technology must implicitly assume that the project as proposed will be effective in achieving a certain level of contact and development. The likely level of uptake can either be based on (a proportion of) the technical potential or on the contact potential of the project (assuming a % uptake and % sustained).

In this case the estimated potential was based, firstly, on the physical potential given suitable geological and climatic zones within the proposed project region (including estate reservoirs). Secondly, a general impression was gained from farmers and development workers in the region, that fish was a valued source of food, and that many farmers (and a number of estate owners) were interested. Third, potential uptake over a five year project life considered information on the adoption of aquaculture in a neighbouring region, where technical advice was available, over the previous 5 years.

The final output figure used in calculating the total economic value of the project incorporated assumptions made in the individual farmer models (average yield), and the regional impact (number of these ponds in operation over a given period, including estate production). It is apparent that, given the broad assumptions made at both a farmer and a regional level, the potential for error in the actual result is considerable, even under favourable conditions for project implementation.

The appraisal concluded that while fish farming appeared to be a very worthwhile activity for individual farmers, the potential scale of development meant that the project was not economically viable on the basis of specified costs and benefits (Beveridge and Stewart, 1986). While lower cost options were outlined, the potential risks to project success associated with these were emphasised (particularly in the appointment of a VSO volunteer rather than an experienced project manager). However, the purpose of the analysis was to present a professional judgement of what might be achieved, and give an indication of the sensitivity of this to changes in the initial assumptions. To this extent, the appraisal fulfilled the TORs as specified, and presented the donor with the information on which a project investment decision could be made.

7.4.4 The limitations of the appraisal and project process

In addition to the information constraints within the appraisal process, there were, in hindsight, significant omissions in the scope of the appraisal, which reflected the limitations in the development project process concerning sustainable aquaculture developments. These limitations are largely associated with the strong technical and sectoral focus at all stages in the process, and by implication the lack of attention to the social and institutional context of the development activity, and the wider resource and activity context of diverse rural farming systems.

This case presents a fairly typical picture of rural aquaculture development programmes in Africa: large investments in project structures seemingly failing to attain the forecast benefits in terms of increased fish production, and with no clear identification of the social and nutritional benefits of that production, although these are often implied in the project justification (UNDP/UNMD/FAO, 1987; Harrison, 1994a). This does not mean that a project such as this would not produced benefits, or that the basis for sustainable aquaculture has not been established: the point is that appraisal and project process did not incorporate appropriate measures to allow an assessment of the potential for sustainability in these terms. In a review of some 39 Aquaculture projects, UNDP/UNMD/FAO (1987) concluded that projects "were appropriate in the sense that the proposed outputs could have contributed to achieving (socio-economic) objectives..", but that many had incomplete rationale in project documents which reflected "little, or scant concern, about the likelihood the effects and impact would ensue once the project outputs were available"

There have since been a number of research programmes in the region which have examined the socio-economic and agricultural context in which these rural aquaculture development projects have occurred (Harrison et al, 1994; Stewart, 1993a &b; Johnson, 1992; ICLARM/GTZ, 1991). Here, the above case is examined in the light of these studies, and developments in approaches to rural agricultural development in general. The issues are discussed below in terms of the following aspects:

- Farmers and beneficiaries: perspectives and roles in the development process.
- Institutional constraints.
- The project concept and the channel of delivery.

This is supported by an overview of issues and problems from perspectives of aquaculture promoters and farmers presented in Table 7.8.

Farmers and "beneficiaries"

Throughout the process described in the above case, the "farmers" had been identified in very simplistic terms, as a homogeneous (male) group of passive recipients benefiting from the introduction of a new technological package. What was missing from this view was a recognition of the diversity of individuals and their circumstances, as farmers, householders, family and community members, male and female. There was no question at the time of any more in-depth analysis of their views, their perceptions of the technology and the development process, their motivations and expectations of benefits, both from digging a fish pond, and from the project. There was also no assessment of the potential impact of this technological development on other members of the local communities in which the developments occur, both in terms of the assumed benefits, and the potential disbenefits at both inter and intrahousehold levels. Evidence from Malawi (Stewart, 1993a &b) and Zambia (Harrison et al., 1994) sheds light on a number of these issues, as follows:

Farmers' motivations for adoption and their expectations of the project. The implicit assumption in the approach to the development described above was that farmers' objectives were based on the same values as those of the appraisers and the development workers delivering the technology (ie profit/ yield maximising objectives). While there is evidence from both Malawi and Zambia that the motivations for adoption in many cases were income and food, more detailed studies have revealed a range of other factors, including raising the status of the adopter, making claims on common land and expectation of material and financial benefits from the project.

Table 7.8 Perspectives on the problem of aquaculture development in Africa: from conclusions to strategy

The tables below are divided into problems as articulated by institutions such as donors and African governments and those articulated by farmers. There is naturally considerable overlap (from Harrison, Stewart, Stirrat and Muir, 1994).

a) ISSUES AND PROBLEMS FROM THE PERSPECTIVE OF AQUACULTURE PROMOTERS

ISSUES/PROBLEMS	EXPLANATIONS/ COMMENTS	RECOMMENDATIONS
1. The development context	-Projects have been created from a wish to see aquaculture working rather than arising from the needs of supposed beneficiaries. -Both needs identification and making the links between these and aquaculture is problematic	-Participatory research on needs for and value of aquaculture in specific contexts. -see section 4 on monitoring and evaluation below
2. Lack of sustainability of project efforts, including collapse of infrastructure	-Inadequate assessment of limitations and priorities of host government department. -Investment in infrastructure may be unrelated to aquaculture's capacity to meet development need.	-Understand institutional legacy: how and why projects failed. -Assess proposals for infrastructure in light of capacity to meet development need. -Focus on institutional strengthening *including* managerial training and *planning* capacity. -Rethink project approaches: greater flexibility, qualitative indicators, more time
3. Problems in extension services: - -poor morale -unable to reach farmers -inappropriate advice	- Lack of incentives, little participation in decision making, dependence on allowances. -Training has been technically and fisheries based	-Investigate more consultative approaches to extensionists training, and from these, options for improved incentives. -Need to establish: Feasibility of training advisers from other sectors to incorporate fish farming in their activities. Training focus on i) Aquaculture within the farming system; ii)Participatory extension methods iii)Socio-economic issues; iv)Technically: production cycles, fingerling supply / restocking.
4. Weaknesses in monitoring and evaluation	-Lack of clarity concerning overall objectives and mechanisms for their achievement. -Failure to incorporate intra- and inter-household resource control dynamics -Data-bases tend to be unreliable and inconsistent	-Information needs should be objective oriented and achievable. -If objectives are mainly poverty oriented: monitor who are taking up fish farming through methods of PRA and sampling. -If objectives focus on the establishment and consolidation of fish farming use qualitative measures to find evidence of: maintained ponds, farmer-farmer fingerling supply. -Use PRA to monitor intra household and community resource control/ management issues. -Assess role of pond as addition to farm rather than as just fish production unit -Data collection should not be main job of extensionists. -Monitor and evaluate training and subsequent deployment of extensionists
5. Farmers do not respond as hoped: i) Failure to adopt ii)Poor management	-There is only a limited number of farmers for whom adoption makes sense. -Less than optimal fish production is acceptable if motivation is not primarily about fish production -Some farmers have capacity and willingness to improve management but need better extension advice -Some farmers have little or no capacity to improve because of poor pond location/construction or limited available inputs	-Understand in advance of support to fish farming: biotechnical factors, other economic opportunities, land availability and tenure, valuation of fish, other potential of ponds, intra-household resource control. -Improved extension through agriculture (see above) -Support rather than "sell" fish farming ("development effect" dangers) -Focus on quality of advice regarding pond construction and location

Table 7.8 (Continued)

b) ISSUES AND PROBLEMS FROM THE PERSPECTIVE OF FARMERS.

ISSUES/PROBLEMS	EXPLANATIONS/ COMMENTS	RECOMMENDATIONS
1. Extension does not meet information needs	-Poor training of extensionists -Extension focused within fisheries sector instead of integrated with agriculture -Where farmers are highly dispersed, meeting their information needs may not be possible.	-Support to training including of agriculturalists (see above) -In areas of high dispersion, train farmers in groups and on-farm. -Ensure group and individual extension is sensitive to different needs and priorities of men and women.
2. Fingerling supply	-Farmers do not know techniques of fingerling production -They have often learnt to expect that supplies will be delivered, by government or project	-Training farmers in fingerling production to encourage farmer-farmer supply. -Support to economically self-sufficient fry production centres in areas of high density of fish farmers to maintain quality. -Unlikely to be viable to attempt to deliver fingerlings to farmers.
3. Theft and predation	- Ponds badly sited and constructed - Ponds poorly maintained - Some theft/predation may be unavoidable	- Attention to pond location (near home) and construction in advice to farmers -With farmers, work out locally appropriate solutions (traps, slashing grass etc). -Because of theft dangers, pond should be only one among other strategies adopted my farmer. Diversification not specialisation.
4. Marketing: lack of marketing channels	-Fish farming has on occasion been encouraged in areas with restricted opportunities for marketing. This matters only if production for sale is primary motivation for adoption.	If farmers require cash gain: focus on areas with marketing potential (demand, infrastructure.
5. Non fish farmers' concerns	Important to consider - Members of fish farming households -Others in the community	In monitoring, assess: -Shifts in resource-control within household as a result of fish farming. Especially: natural resources, time (labour), money. -Changing land values -Changes in control of common property resources

The latter reflects the culture of dependency in these rural farming communities, and to some extent the promises made by the project extension workers: a common response from farmers, whose ponds are unstocked for long periods, or have been abandoned altogether, is that they have been "waiting for a better fish" (or in some cases lower cost fish). This occurs even in situations where fish are available from other farmers. The idea of a better fish, in the case of Northern Malawi (Stewart, 1993a), arose from on-farm trials using alternative species of Tilapia. However, while results of trials suggest small marginal gains in performance may be achieved (about 10%-20%; Brooks and Maluwa, 1993), these are insignificant in comparison to the possible gains from improvements in management in farmer's ponds with the existing species.

Farmers' expectations of the technology. In most cases the performance of farmers' ponds fall well below those which might be expected based on technical evaluations. This has been associated with the perception of many farmers that fish, as in the wild, will grow "by themselves". There is evidence that farmers in these studies did not fully appreciate the level of husbandry required, in terms of inputs and levels of management. The concept of the production cycle was lacking. Fish were often treated as an asset, similar to other livestock. As a result, ponds were often not harvested for long periods, increasing the risk of losses through predation and theft of harvestable fish.

Inter and intrahousehold effects. The assumption concerning project benefits did not consider the possibility of negative impacts, or the question of distribution of these benefits in relation to the project objectives. A number of issues might arise in this context. For example, interhousehold resource conflicts, such as access to water, or common land, can occur, although from the above studies these appear to be uncommon. The assumption that fish production will automatically bring household benefits has been criticised as being over simplistic, as it ignores the importance of intrahousehold dynamics in the control and access to those benefits (Harrison, 1993), specifically where the "owner" of the pond and output is male. The assumption of nutritional benefits to the wider community appears to be misplaced, given evidence that adopters are generally the more wealthy members of the community who have access to other sources of (dried) fish. The more nutritionally needy who can often not afford to buy from existing sources, are unable to benefit from the more expensive fresh fish supplied through aquaculture. These factors are not to suggest benefits are not achieved, and that fish farming cannot contribute to the diversity and stability of rural farming activities, but that the views on which the project was based may have been misplaced.

The farmers' views of the extension services and the project. The predominant view appears to be that these services function as providers, rather than facilitators. This is believed to act as a major constraint to the capacity for the development of an independent and sustainable fish farming sector in these communities. The problem is largely due to, and perpetuated by, the way in which the development process interacts with farmers, in a classic top-down approach.

The lack of recognition of these factors, in the planning and implementation of the extension process and approach, reflects the oversimplistic view of 'smallholder farmers', and is believed to represent a major factor in the poor performance recorded in many aquaculture development projects.

Institutional constraints

Institutional problems which appeared to limit the capacity of the above project to achieve the stated objectives appear to be widespread: lack of resources for field work, and poorly trained and motivation field staff, remain the most commonly cited constraint to the efficacy of extension services. These have been associated with failure to provide funds (lack of government commitment/ resources), administrative delays (host and donor agencies) and failure in project management (and sometimes misappropriation of funds). There is generally a lack of official project documentation on the latter aspects, due to the political niceties of the donor-host relationship. However, at the project staff level, reports of such managerial inefficiencies are the rule rather than the exception.

The project as a channel of delivery

The concept of the project, as manifest in the above case, and most other aquaculture development efforts in the area, can also be a challenged as a means to achieve sustainable development. Firstly, there is the anomaly of fisheries departments delivering messages on a livestock production system to rural agricultural communities, through institutional structures completely independent from the efforts of the agricultural services. The focus on this single technology is also over-simplistic, as the activity being assessed is only one, probably relatively unimportant, of many in the rural farming system. This institutional characteristic is widespread, and reflects historic developments in both donor and host institutions. Although this has been recognised for many years, and most projects propose to work in association with agricultural services, there is little cooperation in practice. The need for extension advice to be based on the concept of the fish farm being an integrated component of a diverse farming system has been widely recognised, but rarely applied in the practice beyond research based projects (eg see ICLARM/GTZ, 1991).

Secondly, the findings of UNDP/UNMD/FAO (1987), which considered that "the planned duration of projects, especially those aiming to introduce new culture systems, has been generally too short for impact to be achieved" appear to still apply to the range of aquaculture projects implemented since that time. This study found that where projects ran for a decade or more, impacts began to emerge before project termination.

Thirdly, the concept of the project itself, as a discrete event, has been criticised. The product of this interface between donors and recipients, ie the outcome of development aid inputs, can not be clearly isolated in the form of individual project cause and effect, but more as an ongoing contribution to change within the social and economic structure of rural communities (Harrison, 1994a). This is not necessarily a criticism of the concept of the project process as a management tool (FAO, 1991), but the inflexible way in which this is usually translated into an isolated blueprint for technology transfer.
The observations made in regard to this case study, and other aquaculture projects, are by no means unique, or even unusual. Cassen et al. (1986) lists five aspects of unsatisfactory appraisal in aid projects in general, which recur with particular regularity, and echo all the features above. These include: overestimation of recipients' capacity for administration and implementation; imprecise forecasting of effects on intended beneficiaries; unrealistic assessment of the time required for project self reliance; lack of understanding of the human, social, and physical environment (suggesting that "most agencies are still reluctant to employ social scientists other than economists on identification missions") and lack of attention to the relation of the project to other projects or programmes. He concludes with the comment that "the disturbing feature of these design and appraisal faults is that they are well known, yet the evaluation literature is replete with complaints that they keep being repeated".

7.5 Summary and Conclusions

In considering to what extent a specific, but typical, project appraisal process addressed the needs of assessing the potential for the development of sustainable rural aquaculture in rural Southern Africa, it must be concluded that the methods employed failed to do so on a number of counts discussed above. This is not to suggest that the simplistic models of farm ponds, the broad technical estimates of potential for development, or the concept of the project formulation as a management tool do not have a place in the appraisal process. However, it is clear that these alone are inadequate as methods by which the potential sustainability of proposed developments can be assessed, and that the problem of sustainability at this level requires a much wider focus than the project, or the project appraisal. In terms of the project appraisal process, and indeed the project process itself, there appears to be a need for a change in view of the role of such processes by all stakeholders, at all stages, including a need for:

- better communications (and understanding of objectives, capacities and constraints) between individuals, and more active involvement of farmers (household members), communities and local institutions.

- a realistic assessment of the institutional capacity and constraints.

- flexibility in the development process, responding to apparent needs and opportunities, rather than providing preset solutions.

There is also a need for process of development assistance to address the problems, in particular the institutional aspects, at higher levels than the project and sector. This later, most critical aspect, is clearly not an issue which can be tackled at the project appraisal level, and is therefore beyond the scope of this study.

Potential Indicators

How can the project appraisal process better address these problems? What potential is there for indicators which will improve the chance of projects fulfilling specified goals? Unlike the technical aspects of projects, which can be specified in reasonable detail, the social and institutional aspects are imprecise, qualitative and subjective. The main themes that have arisen from the above case suggest that "indicators" of potential for achieving sustainable aquaculture development must include some means of incorporating the following aspects:

- the approach to the development process (the flexibility and timescale of the project process; how projects fit into the wider development context).

- institutional capacity and flexibility (managerial attitudes, skills and accountability; extension attitudes and skills).

- participation at all levels of the project process (community / beneficiary involvement in problem identification, and project formulation; farmer based technology modification / development.

- a focus on self sufficiency - minimal dependency on project structure and function.

- a focus on potential distribution of benefits (to what extent does technological interventions influence equity in the rural community, at both intra and inter-household levels).

A number of these aspects are largely concerned with the cultural capital element of sustainability described in Chapter 2. Indicators by which they might be "measured" are likely to be highly subjective. The practical reality of these aspects of change, dealing with individual and institutional behaviours and perceptions, suggests that at best, they represent long term goals, which apply as much to the donor as to the host in development assistance. There will be no certainty that particular circumstances identified with such indicators will produce a "sustainable rural development". However, the process of attempting to address these issues at the appraisal stage, by which the development intervention is defined, is likely to offer a significant improvement on the approach as applied above. The imprecision reflects the imprecision of the goal, but does not lessen its potential importance. These issue will be discussed in more detail in the analysis of assessment methods in the following section.

SECTION 3

ANALYSIS OF GENERIC APPRAISAL METHODS

SECTION 3 ANALYSIS OF GENERIC APPRAISAL METHODS

INTRODUCTION

The case studies presented in the previous section set out to investigate specific issues and development situations in terms of interactions between aquaculture developments and the context in which they occur. Each study was limited in scope, aiming to provide depth of analysis to the wide ranging investigation required in seeking an approach to sustainability assessment for this sector.

The first case examined the role of indicators and monitoring in assessing the ongoing interactions between a specific fish farming operation and the aquatic environment. The role such monitoring in the development of adaptive management systems to cope with environmental change was illustrated, although in this case the management process did not fully respond to the information available. The use and limitations of an impact model to predict levels of change, and the sustainability (in commercial terms) of the system, was discussed.

The second case focused on energy as a quantitative indicator by which different aspects of resource use might be assessed on a unified comparative basis. The particular emphasis was on industrial energy analysis (IEA) methods, although wider boundaries for renewable resource use assessment were considered. While there are methodological problems which limit accuracy of these methods, as a descriptive measure, energy can indicate the extent to which technological options move towards or away from efficiency objectives of sustainability. Their relevance was considered to be greater at the sectoral and macro-economic level than at the project or local levels, as impacts, and factors controlling energy use, operate at these higher system levels.

Finally, the third case examined the project process involved in the provision of rural development assistance, which aimed to create the basis for sustainable rural aquaculture systems, although here the objectives did not appear to have been achieved. The limitations of this process were discussed. Here, lack of attention to the social, cultural and institutional environment, was a major omission in the process. Potential indicators by which these aspects might be brought into the assessment were proposed, although it was acknowledged that many of these will be highly subjective, and involve issues at a wider range of levels, beyond local farming systems and the project process.

The three case studies have touched on certain elements of the economic, social and environmental systems recognised as key elements of a sustainability assessment framework. They have also considered the relevance of a selection of potential indicators and assessment approaches to the process of assessing specific aspect of sustainability. These loosely related to the three classifications of impact (primary, secondary and tertiary) identified in Chapter 4.

In considering the needs of the assessment process, a number of key themes have been identified above:

- there is a need to take a wider perspective on sustainability, as case studies have demonstrated the limitations of specific conventional approaches.

- there is a significant amount of information and range of established assessment methods available which could be used to widen the scope of the appraisal process for sustainability assessment (UNCED, 1992).

- there is a need to bear in mind the three-node description of sustainability, considering that methodologies could:

    encompass all of these - fully embracing;

    encompass only one, or some aspects - suggesting the need for complementary methods.

- trade-offs are a common feature- a zero-sum, or positive sum approach will often include negative and positive valuations. There is therefore a need to measure, balance and agree acceptability relating to change in different objective systems.

The objective of this section is therefore to broaden the study by presenting an analysis of a range of largely generic appraisal methodologies in terms of their suitability to provide a basis for, or contribute to, the process of sustainability assessment for aquaculture development. Given the broad range of methods, developed from different specialist fields, often to meet the needs of specific situations and types of development, a comprehensive analysis is beyond the scope of this study: the aim is to analyse a selection of methods, representing economic, environmental and social aspects of development, against a set of criteria developed for the sustainability assessment process.

Chapter 8 Approach to the analysis of appraisal methods

8.1 Focus of the analysis

Introduction

Sustainability appraisal methods, including those associated with aquaculture, must be seen in the context of the societal structures involved in resource allocation decisions. While the pursuit of sustainability requires that all views must ultimately be set in a global context, and that globally acting institutions are needed (UNCED, 1992), routine decision making tends to be located with individuals, local and national institutions, or regional alliances of national institutions. The focus here concerns the appraisal process at each of these levels. This might involve:

- decisions on individual projects, in the context of other local activities and local development objectives and opportunities.

- assessment at the sectoral level, in the context of other sectoral activities and opportunities, and national development objectives.

It is the latter scale which provides the wider policy and legislative framework in which local decision making is set. How this will fit into the global pursuit of sustainability will depend on the combined effects of local and national systems for all activities, and represents a critical element of the sustainability problem.

Methodologies

In broad terms, the three general sustainability objective systems (economic, social and environmental) provide a useful framework for classification of assessment methodologies (Table 8.1). To these can be added a range of integrated or systems approaches, some of which are also applied as techniques for ongoing, adaptive resource management, so crossing over the boundary between the assessment and the management processes.

Table 8.1 A selection of methods or approaches for project assessment[1]

FINANCIAL AND ECONOMIC Financial (ROI, Payback, NPV, IRR, etc) Cost benefit analysis (CBA) Environmental economics methods (contingent valuation, etc) Cost effectiveness analysis (CEA)	ENVIRONMENT & RESOURCES Environmental impact analysis (EIA) Industrial energy analysis (IEA) Ecosystem (+ industrial) energy analysis (Emergy Analysis) Ecological footprint analysis (EFA)
SOCIAL Social cost benefit analysis (SCBA) Social Impact assessment (SIA) Rapid & Participative appraisal methods (RRA, PRA)	MULTIPLE, INTEGRATED OR SYSTEMS APPROACHES Farming systems research & development (FSR&D)[2] Life Cycle Assessment (LCA)

1 This classification is a simplification, as there is considerable overlap between approaches.
2 FSR&D represents a development approach, rather than a specific appraisal approach.

With increasing emphasis on a systems perspective for sustainability assessment, these different methodologies, typically arising out of different specialist fields, are increasingly seeking to expand their boundaries, frequently resulting in considerable overlap (for example, economic approaches extending to include methods for valuing environmental change; environmental assessment approaches extending to include social and economic methods). Although this evolution might suggest a gradual transition towards some single holistic conceptual model from which unified methodologies might be developed, most of these, in fact, operate well within their traditional boundaries, and demonstrate their greatest effectiveness within these boundaries. Furthermore, for smaller scale development decisions, into which single aquaculture projects usually fall, current practice may well not involve any of these wider appraisal perspectives.

While recognising that each or even all of these generic methodologies may have important strengths in sustainability assessment, it is the aim here to propose and apply a set of rationally based criteria to determine their potential for use in assessing sustainability in aquaculture.

8.2 Criteria for appraisal methods

In developing an operational approach to assessing sustainability of aquaculture developments, the potential divergence between the theoretical applicability of different methodologies, and the extent to which these are capable of having a measurable impact on the development process, must be acknowledged. This applies both to the practical constraints of applying available methods, and the means by which information is identified and transferred to the decision making process. With reference to themes discussed earlier, a set of key criteria can be identified for analysing the applicability of appraisal methods. These are described below:

Scope

The scope of the appraisal should ideally be set in the context of the three principal elements, social, environmental and economic, of sustainability. To what extent does the appraisal method deal with these different components? How does it deal with the different valuation systems which might be applied, particularly for non monetary or unquantifiable values? How is risk and uncertainty handled? Does the approach consider the impact of change in terms of gainers and losers, and how does this relate to social equity?

Scale of application

The choice of methods may depend on scale of the analysis, which may range from individual activities, development projects or programmes, through to sectoral policy at a regional and national level. To what extent do methods deal with, or acknowledge the interconnected and hierarchical nature of natural and societal systems? Are methods generally applicable or appropriate only at specific levels?

Practicability

Methods of appraisal must work in the context of their application. This may be influenced by the background information available, and skills available among those responsible for its application. This may vary considerably. Different levels of rigor are, of course, not chosen simply on the basis of available skills and information, but in practice this may be a real issue. The scoping of the appraisal, for major development initiatives, or particularly sensitive areas, may, for example, require external expertise.

Participation

The participation of those involved or affected by development has been identified earlier as a central feature of the trade-off process which decision making for sustainable development may requires. To what extent do methods involve different stakeholders? Do current users of resources contribute in the assessment process, and to the development of changes in management regimes for resource use?

Transparency

The output of the appraisal must be capable of being presented in a clearly understandable form, in which the assumptions, value judgements, and areas of uncertainty are recognised, so that the sustainability trade-offs which may be involved in decision making are explicit. To what extent are these aims achieved?

Cost

In evaluating new development, it is recognised that change, and new economic activities providing livelihoods, is central in sustainability. Appraisal is not about limiting change, but about identifying issues and making trade-offs. The complexity and cost of the appraisal must not burden the process to the extent that potentially beneficial developments are constrained by the weight of information required to make that judgement. There is therefore a trade-off in the selection of methods and their scope, between the economy of the methods, and their predictive validity. The selection of simple yet powerful factors is therefore crucial.

The investigation that starts with financial and economic approaches, acknowledging their central importance as a basis for any wider analysis of sustainability. The assessment processes which follow relate to environmental and social systems, extending the environmental impact and resource use assessments of Chapters 5 and 6, and the social dimensions introduced within the rural development approaches of Chapter 7. A range of methodologies is examined according to the criteria outline above, leading to the aim of the final overview of their potential for sustainability assessment.

Chapter 9 Analytical based methods

9.1 Financial and economic appraisals

9.1.1 Background

The primary evaluation criteria for most aquaculture developments are financial, and are likely to remain so, although other factors influence the decision to invest, particularly in small scale, diverse rural farming operations, as described earlier. For the investor, the assessment of viability is based on market valuations of costs and benefits, and the application of a range of financial appraisal techniques, set against the criteria of potential returns, and perceived level of risk. At this level, other views of the system, expressed in environmental and social terms, are only important in so far as they may impact directly on the financial performance, and remain within the social/ethical boundaries defined by the investor.

While this simplification does not reflect the full complexity of interactions between the production process and the economic system, it can frequently provide a good enough predictive capacity for the relatively short time horizon in which financial investment decisions are made. For the investor, the longer term uncertainties are of less importance, reflected in the time preference implicit in the discount rate chosen.

Therefore while the market oriented objectives set by the decision maker (here the investor) may be generally fulfilled by the analysis (subject to usual uncertainty and risk), decisions so made may not reflect the broader goal of local and wider scale sustainable development. It then falls to policy makers and planners to set the basic criteria, or boundaries, for acceptable forms of change concerning these non financial aspects. The tools most closely related to those used by the investor are those based on Cost Benefit and Social Cost Benefit Analysis (CBA and SCBA) , which seek to reflect societal value of change beyond the financial boundaries of a project.

The limitations of conventional economic models in addressing sustainability issues has been noted earlier[1]. These ranged from suggestions that the problem lies in defining the boundaries of analysis, to those which consider a conventional economic view of the world to be basically flawed. For the former case, techniques are sought for including environmental values in standard CBA: these include contingent valuation methods, hedonic pricing and production function approaches (including travel cost method), based fundamentally on 'willingness to pay' arguments. Representing studies of individual judgement, these can be considered potentially participative methods, in which values can be assigned, usually not in absolute terms, to provide some form of weighting to certain non market factors. The constraints in applying these techniques include the problems of valuation of non market goods (and subjectivity involved in methods applied); ecosystem complexity; uncertainty and irreversibility; the issue of discounting the future and the potential for institutional capture (Hanley and Spash, 1993; Tientenberg, 1988; Winpenny, 1991). These issues have been discussed in Chapter 2.

Given the breadth of debate over the use of economic tools in valuing non market aspects of development, it might be concluded that at best they could only seek to incorporate some environmental values. All intangible elements of environmental support may be beyond their scope (van Pelt, 1992), and so they would ultimately be unable to address fully the issues of sustainability. This might also apply to social and cultural aspects, though a deficiency in only one area would be sufficient to disqualify an approach as a complete sustainability method. Nonetheless, as decision making is usually heavily geared towards economic criteria, it is arguably useful to attempt to address these issues from within established practice. What is important is that economic exercises to create models to produce 'optimal' activity levels (or pollution levels) are not used as the sole criteria for decisions when there may be other relevant factors which, due to inability to produce a value function, are excluded.

A less methodologically suspect method involving a partial economic approach is Cost Effectiveness analysis (Tientenberg, 1988): ie the analysis and cost based comparison of alternative means to achieve a specific goal. As such, the goal itself (e.g. a specified water quality standard) does not need to be valued, but does need to be established by some other means of assessment, and arrived at through a decision making process

[1] Practical limitations in the context of rural development project appraisal were described in Chapter 7; more general limitations were discussed in Chapter 2.

9.1.2 Use of economic approaches in valuing environmental impacts of aquaculture

The potential for impacts of pollution to be directly internalised in terms of costs to the firm were demonstrated in Chapter 5. However, this was a rather extreme case, and a financially unsustainable operation. What is of more concern is the cost to society of impacts generated by firms, which are not sufficiently serious to influence the behaviour of those firms.

There have been attempts to use economic approaches to internalise the cost of aquaculture pollution. Thus Folke et al. (1994) estimated the cost of nutrient discharges of salmon farming in Sweden. The valuation was based on available data for the unit marginal cost of reducing nutrient discharges from new municipal sewage treatment plants by 50%[1]. Applying this to discharges at the level of the firm increased total (economic) production costs to a level which exceeded the highest price paid for the product in the 1980s (at SEK 30/kg), with an even larger margin between costs and benefits in later years (in 1991, the average price was SEK 20/kg, at which time many operations were not viable on financial criteria alone). Based on this analysis, and their emphasis that it internalised only part of the environmental costs of the industry (see Chapter 4), they concluded that "salmonid farming.... is not only ecologically but also economically unsustainable".

Analyses such as this offer potentially useful contributions to policy level debate, when assessing overall sectoral policies in the context of wider national objectives. For example, the above case suggests that initiatives to support rural development through assistance to salmon farming may be in conflict with policies aimed at pollution reduction, and, on this criteria, may therefore be undesirable. An extension of these lines of approach in policy matters would be to apply a polluter pays principle- through means such as discharge permits, or a charge on production. However, this could make the industry commercially unsustainable. It is therefore apparent that caution needs to be

[1] The context of this valuation was the recognition of the significant economic impacts (primarily on commercial fishery yields) resulting from eutrophication in the Baltic, and recent government targets to reduce this impact by upgrading sewage treatment processes. The cost, in terms of reduction of nitrogen and phosphorus output, represents the society's 'willingness to pay' for environmental improvement. Therefore fish farming, which adds nutrients, counteracting reduction efforts, is in effect placing additional costs on society.

applied in the translation of these economic interpretations of environmental impact into the wider policy framework, which must include valuation mechanisms for other aspects of the system.

Firstly, what are the 'external' benefits of this industry to rural communities, and what societal costs would be incurred if policy changes rendered this activity commercially unsustainable (eg. increased unemployment, and secondary economic and social impacts in rural communities). Secondly, the pollution from fish farming should be assessed in relation to other sectors, and other means to fulfil the pollution reduction objectives: it may be that an increase in pollution from growth in aquaculture could be counteracted by reductions in other sectors, with greater overall economic benefits than reductions or restrictions on aquaculture[1].

Wider application of the above approach, which values impact based on output, rather than environmental capacity, can only contribute to policy development where there is a sound basis for that valuation, implying the extent of that capacity has been identified: the same criteria or values would not necessarily be appropriate in other situations. Thus, in the west of Scotland the economic cost of nutrient discharges from marine fish farms is likely to be considerably less significant than in the Baltic, due to the greater capacity of the relatively open coastline to assimilate such pollution.

A theoretical analysis of application of the polluter pays principle to the Scottish fish farming industry has been presented by Soley et al. (1992), but the study lacked a specific context for valuation. Though the authors call for more research into the these aspects, it could be argued, in the absence of any indication of serious impacts associated with fish farming in particular, that this level of analysis may be irrelevant; it could be criticised on cost-effectiveness grounds. What may be more important is the wider issue of total impacts of human activities on coastal resources in general, an analysis of which may include aquaculture amongst other pollution sources.

[1] There may, however, be other constraints (social preferences) which already limit salmon farming in a particular location (chemicals, genetic and disease interactions, predator control), implying the need to consider a hierarchy of constraints, in which dominant features will vary with development situation.

FAO (1993b) presented such an analysis in the context of policy formulation for proposed aquaculture development in Cyprus. A recent fish farm development was reported as cause for much local concern when it was assumed that algal blooms along tourist beaches were caused by the farms effluents. However, the appearance of the bloom, and the development of the farm, were believed to have been coincidence, as additional nutrient inputs were negligible in comparison to existing inputs from agriculture and tourism. Indeed, an analysis of the nutrient enrichment from these sources, and the gross value to the local economy, suggested that in terms of nitrogen enrichment (the main limiting nutrient in sea water) per unit value, fish farming would contribute about 1% and 5% of the inputs associated with agriculture and tourism respectively (FAO, 1993b). Thus contrary to the public perception, if minimising nutrient impacts in relation to economic benefits were a principal criterion for new development, this analysis (based on cost-effectiveness principles) suggests aquaculture to be more favourable than expansion of the two main economic activities.

Establishing relative importance of environmental impacts of different activities is essential in the development of rational policy for minimising environmental costs, while maximising economic benefits. However, the comparative valuation of inputs from different sources again does not consider the capacity of the receiving environment, and the related marginal costs which might arise from additional inputs. This valuation process is complicated by problems of unpredictability. Firstly, due to threshold effects, the marginal costs of pollution may vary widely, and become particularly significant as capacities reach certain indeterminate limits. Secondly, in circumstances of high loadings, other factors, such as the levels of trace nutrients, may become more critical than the standard measures of enrichment (phosphorus, nitrogen, biological oxygen demand)[1]; thus small increases in other inputs which are not included in standards for waste control, and may not be recognised as critical, may induce major changes in the system. Thus while the above approaches to valuation may have an important role in assessing the economic costs and relative values of different sources of pollution, in certain circumstances their ability to capture the true nature of those impacts, and associated values, may be limited. Such valuations also represent just one aspect to be considered in the development process.

[1] In the case study in Chapter 5, it appeared that the level of waste loading was beyond the predictive capacity of the phosphorus loading model applied to the system.

9.1.3 Application to sustainability assessment

Traditional financial and economic methods of appraisal will remain key elements in assessing activities at all levels, from the firm to sectoral analyses. As such these appraisal will continue have a core role in identifying the basic 'willingness to develop' at the level concerned. The evaluation of these methods, in the field of environmental economics in particular, is discussed in the analysis below.

Scope

The scope of environmental economic approaches is strongly set in the economic sphere with extension into social and environmental aspects. The use in terms of incorporating environmental effects beyond those of direct economic significance, or with a very clear basis for the valuation, is extremely limited in the context of aquaculture developments.

Scale of application.

At the level of the individual firm, extended economic approaches are of limited value as the aquaculture industry typically comprises relatively small businesses which individually will have small impacts. This does not mean that the external effects, negative or positive, of a single firm will or should be ignored, but that extensive and formal approaches to their evaluation using economic methods may well not be justifiable.

These methods are likely to be of more relevance at the policy level, determining the economic benefits or costs to society of a particular sector (present and potential future role) in the context of other sectors, national resource accounts and development policy. However, accounting for environmental impacts, for example, will only be possible if there are clear means by which to attribute an economic value, as in the Baltic sea case above. Again, this does not mean these aspects should be ignored, but that they could be dealt with through another aspect of the analysis.

Development projects (ie activities designed to stimulate development of a particular activity or sector, in a specific region), will fall somewhere between firm and policy levels in terms of potential relevance of these methods. In the absence of a higher, policy level analysis of environmental and social externalities of a particular sector, a project level analysis may be relevant where there are clear means to attribute environmental economic values.

Participation

At current levels of application, while environmental economic approaches may require inputs from various stakeholders in terms of attributing values to non market aspects of the assessment, this participation, as presented in the final analysis, can be considered to be at best a limited representation of the range of views which may apply to the development process. However, as a quasi formalised approach to valuation, in terms of measures of individual judgement, this can be considered participative within the boundaries set by the method, which with increasing refinement in methodologies, may be a means of avoiding formless and irresolute public participation. Furthermore, this process may provide structures for common understanding: the fact that one community has a specific willingness to pay for a particular feature may have significance for other similar communities and contexts.

Transparency of output

While information presented in the final analysis, in the form of a bottom line monetary value, will tend to hide the assumptions and value judgements involved, in principle, the mechanisms for the analysis are relatively simple. Thus such analyses should allow for a reasonably transparent view of how a particular outcome was derived, given explicit statement of assumptions made, which can then be questioned. The perceived problem of lack of transparency may be more to do with the way economics present relatively simple relationships in complex 'language'. In considering this feature of any assessment method (thus keeping this point in mind for the later analyses), the transparency to whom, professional or lay-person, and the role of communicating the information, must be established in formulating the means, and detail of content, of that presentation.

Practicability

As these approaches are based on the extension of well established financial and economic appraisal methods, it is likely that in most circumstance the skills required to apply these methods will be available. However, the skill, and value judgements, used in drawing up the assumptions and valuations for environmental aspects are, at present, major limitations: there is also a need for an element of caution in placing to much weight on these valuations, which due to the complexity and unpredictability of the systems involved may not capture the real factors of importance.

Cost

Assessing the cost of implementation here, and for all subsequent analyses of methods below, is limited, as in practice this will depend on the required scope of assessment, and the information available. Applying these approaches to available data, such as the analyses of fish farm impacts considered above, need not be costly in relation to the economic importance of the activities and resources they represent. Costs will, in general, be high for a comprehensive analysis where data is limited, and primary research required to establish values of environmental externalities. However, the principles derived from specific studies may, to some extent, be more generally applicable, at least to the level of primary screening.

Overview

Traditional financial and economic processes are likely to be a fundamental component of any sustainability assessment. However, extended environmental economic approaches alone will not measure sustainability, as not enough elements of the system can be encompassed in a meaningful way into the method. What is important therefore is not the question of methodological deficiencies, but that any analysis is presented in a form which clearly states the assumptions made, the areas of uncertainty and sensitivity to changes. The language and means of presentation of this information to non specialists in this area is an important element in developing the role of these approaches to contribute to wider understanding of their use. Furthermore, the limitations of economic criteria must be recognised, and taken as only one piece of relevant information in decision making.

9.2 Environmental impact assessment (EIA) methods

9.2.1 Background

The environmental impacts of aquaculture development were discussed earlier, the case study in Chapter 5 emphasising impacts of nutrient outputs on the aquatic environment, and the implications for a commercial farming operation. Methods for modelling these impacts were discussed. Environmental Impact Assessment represents a more generalised methodology, providing a framework for these more specific modelling approaches. EIA might have been relevant to a case such as this, particularly in the initial development stage, but also potentially during the operation of the project. The objective here is to present an overview of the formalised approaches of EIA, of which there is a very wide range of specific approaches, and methods of analysis and presentation. The following analysis is therefore focused on selected and relevant elements and features, rather than providing a comprehensive assessment of EIA methodologies.

EIA is defined by Wathern (1988) in broad terms as

> " a procedure for assessing the environmental implication of a decision to enact legislation, to implement policies and plans, or to initiate development projects".

and, based on the definition of Munn (1979), as:

> "a process for identifying the likely consequences for the biogeophysical environment and for mans health and welfare of implementing particular activities and for conveying this information, at a stage when it can materially affect their decisions, to those responsible for sanctioning proposals"

Recognition of the importance of the social aspects of impact assessment, and the apparent failure of early EIA approaches to incorporate these, gave rise to the associated discipline of Social Impact Assessment (SIA) (Carley and Bustelo, 1984; Interorganizational Committee, 1994). This is focused on the demographic, social and economic aspects, and attempts to complement the largely biophysical information generated by many EIAs. The focus here is on EIA, although SIA is based on the same general framework and may be included as a component of the EIA.

While EIA and SIA have been developed as tools of project planning, they are equally applicable at other levels. However, according to Wathern (1988), little experience yet exists of their use for assessing legislation, programmes, policies and plans. It is also important to recognise that these impact assessment processes are not just a range of technical and social evaluation procedures. They are also part of the decision making process, and as such can be regarded as an "art" as well as a "science" (Kennedy, 1984, in Wathern, 1988)

The process of EIA was first adopted in the United States of America under the National Environmental Policy Act of 1969. Much of the stimulus to early developments of EIA techniques arose due to the success of environmental groups in using litigation to force federal agencies to adopt EIA in the decision making process. A number of other countries adopted EIA procedures during the 1970s and 80s (eg Canada, Australia, The Netherlands, Japan, Colombia, Thailand and the Philippines). In 1985, the European Community "finally adopted a directive making environmental assessments mandatory for certain categories of projects after nearly a decade of deliberation" (Wathern,1988).

9.2.2 The process and its components

In general terms the EIA process should perform four tasks: impact identification, impact measurement, interpretation and communication to information users (Wathern, 1988). The relevant stages in the process can be broadly summarised as follows:

- Screening: is EIA required? (legislative requirements for type and scale of project).
- Scoping: statement of terms for a detailed assessment required (focused on preliminary assessment of major impacts and approaches to be used).
- EI analysis: environmental effects of a project analysed; this represents a wide range of approaches and tools, which form the body of EIA literature.
- EI statement (EIS): the documentary report by which the EI assessment projects the process into the decision making arena.

There is great diversity in the approaches used in EIA, many of which have been developed to meet the needs of specific sectors and tasks. Table 9.1 classifies these into broad categories, based on methodology reviews by Shopley and Fuggle (1984) and Bissett (1988). These categories are not mutually exclusive, some representing features or combinations of other approaches. Features of these categories, though generalised, have also been summarised in terms of quantitative, qualitative and visual methods of presentation, and the level of participation in the process. In practice, the degree to which these features are represented will vary greatly with the specific approach taken, and circumstances of the assessment. The classification of participation must also be clarified. The output of the process of EIA, the EIS, strictly speaking, is a consultative document, the objective of which is to present results to stakeholders, including decision makers and public. This is the opportunity for representatives of various interest groups to "participate" in the decision making process. However, the process of the analysis itself, in many cases, remains within the realm of technical experts. The process of consultation of public opinion is not necessarily participative (as discussed later).

Table 9.1 EIA: an outline of main approaches and features

Approach	Features[1]				
	QT	QL	VIS	PAR1	PAR2
ad hoc approaches		*			
Index approaches					
checklists					
descriptive		*			
Scaling	*	*			
Weighted scaling	*	*			
Multi-attribute utility theory	*	*			
Matrices Presentational		*			
Mathematical	*	*			
Input- output	*	*	*		
Mapping / overlays/ (GIS)	*	*	*		
Systems approaches					
systems diagrams/ networks		*	*		
ecological systems modelling	*	*	*		
simulation modelling/ Adaptive methods (AEAM- adaptive environmental assessment and monitoring	*	*	*	*	

[1] QT, quantitative; QL qualitative/ subjective; VS, visual representation; PAR1, participation at professional /political level; PAR2, participation at PAR1 and public level (the latter not including consultation, surveys, or public enquiries).

9.2.3 EI analysis: strengths and weaknesses of different approaches

Bissett (1988) divides methodologies into a number of categories, characterised as follows.

Index approaches

These include methods based on checklists and those approaches based on multi-attribute utility theory. Checklists can range from lists of environmental impacts to be considered in assessing a development, to adaptations which transform the range of impacts to units on a common notional scale, weighted in terms of relative importance, and combined to provide an overall index of total impact. Bissett (1988) has considered the application of multi-attribute utility theory to the checklist framework as a "means whereby possible environmental consequences can be traded off". This involves the determination of the range of environmental attributes, and related impacts, which can be measured, and the application of preference structure, in the form of a utility function (eg on a scale of 0-1, where 1 is the highest utility value), regarding the relative merits of different levels of each attribute[1]. Having established functions for individual aspects, they can be combined to give a total expected change in utility associated with project impacts. By providing a "score", it provides an easy basis for the decision making process. Sensitivity analysis can also be applied easily to demonstrate the impact of changes in utility assumptions.

The main criticisms of index approaches are:

- the subjectivity involved in the valuation of the environment (usually by a limited number of 'experts' or decision makers). A further point is that the need for quantification may lead to attempts to quantify the unquantifiable.
- the lack of transparency of the final amalgamated result, which limits the potential for public participation in the process.
- the process of treating the environment as a list of dissociated factors which can be evaluated in isolation, and then aggregated to produce a final result, belies the complexity of environmental systems.

[1] Bissett (1988) presents an example in which 100% loss of salmon leaving natural waters due to a power station development might be considered very serious, and be attributed a utility value of 0, while an 80% loss might have a utility value of 0.5.

Systems Diagrams

Systems approaches to EIA have been developed in the field of ecological energetics (Odum 1983), essentially building from the concepts discussed earlier. The advantages of these approaches are that they acknowledge the interconnected nature of environmental systems, and by the use of energy flow, can provide a common unit of value for comparing impacts. Attempts to relate these energy flows to cash values of the economy, by which a (notional) cash value of change in the environment can be assessed (Odum, 1988) have also been discussed earlier. The drawbacks, listed by Bissett (1988), include the cost associated with the complexity of making the assessment, the fact that not all important ecosystem links and functions can be characterised by energy flows, and that this approach is largely concerned with the ecological impacts, generally neglecting socio-economic aspects.

Simulation modelling

The use of simulation modelling in EIA was first introduced by Holling (1978). The procedures of Adaptive Environmental Assessment and Monitoring (AEAM) involves the simulation of project impacts and implications based on the inputs of a range of specialists and policy makers. Through the process of model development and simulation runs, key features of the potential impact, and requirements for further data collection and research, can be identified. The method does incorporate the inter-connected nature of the environment, and can be valuable in providing the focus for debate between parties during model development and simulation exercises. This approach tends to have been used for management of economically important natural resources. However, there are still disadvantages in the need for quantification of impacts, and a tendency to focus on the ecological aspects, at the expense of social and economic concerns.

Common features

Common to all scoring methods, are, (to varying degrees):

- subjectivity involved in assessing aspects of environmental value or utility, when it comes to the production of quantified (or scored value) impacts;
- lack of understanding of the complexity of interrelationships in environmental systems; problems of uncertainty, in terms of predicting the consequences of change.

- problems in incorporating the human element, the social and economic considerations, associated with major developments (health, community change).
- lack of post EIA assessment of the methods and outcomes.

9.2.4 EIA-based decision making (the art of EIA)

EIA as an approach, and a collection of methods, has considerable potential for identifying means for reducing impacts of development. However, it is also part of the political process, and may be subsumed within it, which may limit the extent to which it can contribute to the development of more sustainable activities. Firstly, and possibly most significant, is the fact that the environmental impact statement (EIS), as an output of the EIA process, is usually presented as a separate and discrete analysis, commonly after the conventional financial proposal or socio-political development decision. It represents only one set of information to be evaluated. Against the competing demands of immediate (perceived) economic and social needs for development, environment will often take a relatively low priority.

Secondly, the benefits of an EIA depend greatly on the attitude of the proposers of development, on the agents chosen to carry out the EIA, and on the extent to which it is incorporated into the planning, development and ongoing management of a project. Wathern (1988) observed that EIAs carried out by the proposers can offer potentially greater scope for the process to reveal alternative means of achieving project objectives with less environmental disruption, that those carried out by an external agent, who may have less insights on the technological alternatives. Furthermore, given the great uncertainty in forecasting[1], particularly secondary and higher order impacts[2], it may be desirable for impact monitoring to continue during the development and operational phases of many projects. While there is evidence from the USA that the costs of EIA preparation could be more than covered by the savings arising from project modifications, in many cases developers regard the process as a financial burden. Often the primary purpose of the EIS is seen as a means of avoiding litigation (Wathern, 1988).

[1] discussed in the context of impact models in Chapter 5

[2] secondary in this case refers to sequential effects arising from direct impacts, rather than the impacts on other systems, generated by demands for inputs, defined in Chapter 4.

At this point the EIA process, as an exercise in compliance, is seen to be a complete and self contained exercise, rather than forming an integral component of an ongoing and adaptive planning and management strategy.

Finally, while EIA does allow for public involvement at certain stages in the process, (in USA 95% of EPA projects involve public meetings), Wathern (1988) has argued that "the high incidence of litigation .... suggests that people consider such meetings as inadequate mechanisms for incorporating their concerns into a project". As suggested above, none of the methods appear to be particularly participative in nature.

9.2.5 EIA Applications to aquaculture

To date there is little evidence of EIA procedures being applied to aquaculture developments (Beveridge et al., 1994): in most countries EIA has only been adopted relatively recently[1], and many aquaculture projects are out-with the scope of legal requirements for EIA. Thus, in Scotland, most of the expansion of the aquaculture industry occurred prior to the UK implementation of the 'EC Directive on Environmental Assessment' (EC85/337/EEC, 1985) in 1988 (HMSO 1989). Furthermore, the criteria for screening are so broad that subsequent developments have not been included[2]. This does not mean that fish farm developments in Scotland are, or have been, exempt from planning regulations which include assessment of environmental impacts: marine development may require up to 6 different permits, issued by different agencies (Burbridge, et al, 1995). Thus Wathern (1988) noted that while the UK was slow to adopt EIA as proposed by the EC directive, the government maintained that the elements of EIA were already present in a flexible guise in existing provisions under Town and Country Planning legislation (HMSO, 1988), which requires all development to seek approvals unless specifically exempt (the latter including forestry and agriculture, but not aquaculture). Major limitations in this process for aquaculture planning arise due to the lack of a lead agency, and the lack of standardised procedures among agencies, or even within individual agencies at the regional level (Burbridge et al. 1995).

[1] Countries which now include aquaculture in formal environmental legislation include the UK, Ireland, New zealand (Beveridge, 1994) and Canada (Black, 199)

[2]According to a recent survey, no Environmental Statements have been submitted by any of the 446 registered businesses operating 721 sites in Scotland (Burbridge et al., 1995).

A further limitation of the EIA process, as currently applied, can arise due to the combined effects of large numbers of small developments. Therefore while individual projects might have limited impacts which do not fall within the requirements of EIA legislation, at a development level these impacts may be more serious. In Thailand, a legislative framework for EIA was adopted in 1978 in an amended 'Improvement and Conservation of National Environment Quality Act, 1975' (Htun, 1988). However, the categories of projects subject to EIA were large scale industrial and infrastructure developments, dams (greater than $15km^2$), and irrigation projects (greater than 12800ha). There was clearly no coverage of aquaculture developments, which have proved to have had very significant impacts on coastal environments (noted in Chapter 4). Although examination of individual projects may not have appeared necessary, the need may have been judged differently had a sectoral focus been taken. This illustrates the problems associated with the assessment of individual projects without considering the wider impacts of other similar, or unrelated, developments in the same environment. It also suggest that applying EIA at the policy level, as part of a pre-emptive sectoral and coastal resource planning process, might have provided for a more sustainable development of these resources.

An important aspect of the EIA process is the potential for feedback to the design or management of the activity, by which the means of reducing impacts might be identified. In some cases this may also improve commercial performance, as suggested earlier. Here, the development of appropriate monitoring is important, both at the level of the firm, and for the sector as a whole. The feedback and adaptive management process is also important when dealing with issues of potential concern, or uncertainty.

For example, evolving management practice can be seen in the pattern of use of chemicals and antibiotics in salmon farming. In the UK, calls to ban the use of organo-phosphorus compounds for treatment of sea-lice, if implemented in the short term, would have a devastating effect on the viability of the industry. However, concerns over their use, the threats of such bans, and the declining performance of farmed stock, have contributed to the process of change in management practice to reduce the need for treatments (eg site fallowing)[1], and increasing research for alternative treatment methods

[1] Guidelines here have been developed largely by operators (Burbridge et al., 1995)

(biological control using wrasse, vaccine development).

A similar example concerns the use of antibiotics for disease treatment. During the 1980s, increasing disease problems in the salmon farming industry was accompanied by sharp increases in the administration of antibiotics, with increased concern about potential negative effects both among the scientific community and environmental pressure groups. In Norway, for example, antibiotic use reached a peak of over 40 tonnes in 1988 (when total production was about 80,000 tonnes). Since then, changes in management practice (fallowing, reduced stocking density) has reduced problems of disease outbreaks, and the need for treatments, so that antibiotic use in 1993 had fallen to about 5 tonnes, while production had increase to 150,000 tonnes (Beveridge, 1994). This change not only brought considerable savings to the industry, but also reduced the potential (although unknown) impacts on other marine coastal resources, and on the welfare of people (potential microbial resistance).

In shrimp farming similar concerns regarding antibiotic use have been documented by Brown (1989) and Brown and Higuera-Ciapara (1991). The inability of treatments to effectively deal with the problems of disease, and market pressures and regulation of product quality (concerning antibiotic residues) have played a significant role in the search for improved management regimes. The fish farm impacts on water quality in freshwater bodies have also been significantly reduced over a number of years by the reduction of the phosphorus content of manufactured feeds (Beveridge et al, 1994).

While none of these three cases had anything to do with specific EIA procedures, they indicate the way more explicit procedure might function and create necessary feedbacks. When considering this potential function EIA in this role, through the identification and development of policy, there is a need to balance potential control measures with the needs of industry. In this respect flexibility in policy may be desirable, in the event that impacts are more serious that initially envisaged. Such flexibility implies that consents for specific activities or discharges may change over time. An important factor in adaptive resource management policy is the need to consider the social and economic implications of changing regulations on the viability of economic activities.

9.2.6 Application to sustainability assessment

Scope

As applied to aquaculture, conventional EIA tends to focus on the impacts at the development site and local area, concentrating on the local input/ output features of the operation. These approaches therefore consider only some of the issues within the environment sphere of sustainability. The requirements for inputs, and the wider impact on renewable and non renewable resources, are generally not represented. Economic and social spheres are important in determining the significance of the environmental impacts, but, as applied to aquaculture, the approach does not generally place much emphasis on these aspects. In theory, however, these can be addressed by incorporating other impact assessment methods into the process.

Scale of application

At present EIA is principally applied at the level of the firm, restricted to large scale industrial developments and engineering projects. In some cases it required for large scale aquaculture developments (eg for UK see HMSO,1989; Burbridge et al., 1995).

At the level of the firm, some form of environmental screening will be an important component of any sustainability assessment. In many cases this would involve simple input output-models, as described in Chapter 5. The need for more detailed analysis would depend on the results of screening. In the case of the current approach to planning in Scotland, the argument that existing legislation provides a framework for such assessments would appear to be reasonable, but for the lack of a leading agency by which requirements for assessment and monitoring may be standardised.

This does not mean that wider assessment of the potential economic and welfare implication of impacts of aquaculture developments are unnecessary, but that the proper context may not be at the level of the firm, unless specific circumstances suggest significant effects.

At a policy level, nationally and locally, the use of EIA, based on specific studies, and the analysis of the sector as a whole, may provide useful perspectives on policy formulation and natural resources management regimes. However, at this level the impacts of aquaculture would need to be set in the wider context of other activities and users of aquatic and other relevant resources, again suggesting the need for a leading agency to develop integrated resource management planning

The potential for EIA to contribute to technological change and reduction of impacts, by identification of areas of uncertainty, and monitoring requirements which can be integrated into the development and management process, will be relevant at both firm and sectoral levels.

Participation

The tendency for limited participation in the EIA process as applied to date has been discussed above. However, as a framework for the assessment process, there is no reason why increased participation, as appropriate, can not be incorporated in applying EIA as an approach to sustainability assessment. There will, however, remain aspects of the assessment which will remain within specialist fields.

Transparency

The form in which the information of the EIA process is presented in the EIS can vary greatly with the specific methods employed, lack of transparency being a commonly cited weakness, as suggested above. In theory, one of the roles of the EIS is to communicate specialist analyses to other stakeholders. In practice, problems of complexity and uncertainty inherent in environmental systems, and the qualifications this may require in data presentation, can limit the extent to which this is achieved, particularly where scoring methods are employed, implying value judgements in the processing of data. For aquaculture developments, however, there would appear to be potential for the presentation of many of the broad contextual feature of impacts in a relatively simple manner. In comparison to the economic assessments, the EIS is likely to offer the potential for a more explicit recognition of issues beyond those which can be easily incorporated into economic approaches.

Practicability

The skills required for the implementation of EIA will vary with the extent of the analysis, and in many circumstances these may be lacking. Again, uncertainty in the response of environmental systems to change, and in many circumstances a lack of data, may make the prediction of the wider environmental impacts a significant problem: this applies in particular to impacts concerned with chemicals, drugs, and the interactions of escaped farmed stock in the local ecosystem. However, as an approach to identification of areas of uncertainty, and descriptions of impacts concerned with site and water requirements and water quality, procedures can be relatively simple. As such, the process of EIA is likely to represent a major contribution to the assessments of sustainability, which, as identified earlier, is about making information available for decision making, including aspects of uncertainty.

Cost

As with economic approaches, the cost of the implementation of EIA, and any environmental monitoring, will vary greatly with the scope of the analysis. In many cases, at the level of the firm, relatively simple analyses and monitoring may be sufficient to provide information which can be used in the context of local resource management regimes. At a sectoral level, more detailed research may be required to deal with certain aspects of environmental uncertainty. Relative to the importance of the industry, the implementation of such information requirements need not be prohibitively expensive. In addition, there may be a degree of transferability of results of research from other sectors. At a practical level (ie making the most of current knowledge) for all scales of application, there is a need, and potential, for simplicity in approach (implying reasonable cost), buy which main relevant features can be identified and incorporated into decision making.

Overview

By widening the boundaries of project assessment beyond the realms of the financial and economic criteria of the specific activity, and by providing the mechanism for feeding this broader view into the decision making arena, EIA potentially moves the evaluation process towards a more holistic approach advocated by the concept of sustainability. It is subject to limitations, in both the 'science' (the tools themselves, and the complex and uncertain nature of the systems being evaluated), and the 'art' (users of tools and information). It can clearly help in identification of characteristics of systems which might suggest they are more or less sustainable, on a range of criteria, or aspect of sustainability. As such, the potential for EIA to contribute to the analysis of sustainability of a particular aquaculture system, or technology, will depend on the existence of appropriate criteria, set in the wider context in which the development occurs. The conventional level of application (as a discrete, project base, post-hoc analysis), however, represent a major constraint to the usefulness of this process in achieving more sustainable development: ideally, this approach needs to be part of a strategic, proactive approach to development planning.

Thus as a process, the conceptual framework and approach of EIA appears to provide a reasonable basis for the development of sustainability assessment, although the boundaries of the analysis would need to be extended to include other, non environmental assessment methods.

9.3 Resource use assessment: Energy and Ecological footprint analysis

9.3.1 Background and approach

The concepts and approaches of using energy as an indicator of renewable and non renewable resource use efficiency, and their uses and limitations for sustainability assessment, were discussed in detail earlier. The objective here is to examine an integrated approach, Ecological Footprint Analysis (EFA), in which the tools of energy analysis are applied. This has been advanced by Rees and Wackernagle (1994) as a "novel approach to estimating the natural capital requirements of the economy based on consideration of human carrying capacity" representing "an alternative empirical approach to the optimal stocks question". It is based on the idea that "for most types of material and energy consumption, a measurable area of land in various ecosystems is required to provide ... resource flows and waste sinks".

In this context carrying capacity is defined as "the maximum population of an organism a given habitat can support indefinitely" and could therefore be related to the ecological sustainability of a human population living in an isolated region. However, in the context of the connected nature of global ecosystem support to human populations, EFA reverses the carrying capacity concept to consider the resource flows, essentially related to land area (except for fossil fuels), required to sustain a population living in a given area. The question of fossil fuel (non renewable resource) subsidies to human activity is accounted for in terms of "energy land" in one of two ways: either the land area required to generate equivalent amounts of energy through renewable biomass (assuming eventual reliance on renewable energy sources), or alternatively, the area of forested land required to absorb the carbon emissions of fossil fuel combustion. Applied at regional and global levels, this approach can demonstrate the scale of the limitations of the global carrying capacity, and the inequities in present North-South relationships, the former being highly dependent on the latter for ecosystem support to present consumption (Rees and Wackernagle, 1994).

Of more relevance to this study is the application of this approach to the analysis of ecosystem support to individual production activities. Essentially this represents a modification, or an extension of, the ecological systems analysis approaches of Odum

(1983, 1988), potentially incorporating industrial energy analysis, and translating energy requirements into land area requirements.

Applied to aquaculture production systems, it has been estimated that the area required to support semi-intensive shrimp production is 35-190 times the pond production area (Larson et al., 1994). This includes mangrove area required to supply larvae, purify water and supply organic detritus which supports pond production (20 -170 times the pond area), and sea surface area required to produce feed (0.2 km^2 per tonne of shrimp, supplementing natural productivity of the pond). In the case of intensive salmon farming, the productive area of continental shelf waters required to provide feed alone is estimated at about 40,000 -50,000 times the culture area or, 1km^2 per tonne of fish produced (Folke, 1988, Folke and Kautsky, 1989, based on North Sea productivity). Applying these figures to the Scottish salmon farming industry suggests an ecosystem support area for feed alone of about 50,000km^2.

Practical applications of EFA have been suggested by Larson et al (1994) in the case of the shrimp industry in Colombia: while in pond area terms the present industry appears to be relatively small in comparison to the available coastal resource, the EFA suggests that at the present scale the local coastal environment is already being fully utilised, implying that further development could not be sustained. This conclusion considers local ecosystem goods and services noted above, but not the imported resources from other systems (including stock from overseas mangrove ecosystems, and fish feed), which effectively represent management problems in other ecosystems. These authors qualify the capabilities of EFA in contributing to meaningful management by recognising that similar analyses must be applied to other activities which used the same ecosystem. Furthermore the analysis must establish the extent to which various activities may compete with, or complement each other in ecosystems support: ie a multiple use ecosystem perspective is advocated.

The methodological problems in applying this approach (in addition to those identified by the authors above) include those of data availability, complexity and uncertainty[1], and are manifest in a number of ways.

[1] ie those limitations of the underlying methodologies involved in assessing ecosystem structures and functions and industrial energy inputs, considered earlier.

Firstly, in the above example, it is suggested that the local environmental capacity to support this activity is fully utilised: but how reliable are these figures, what are the margins of error, and what are the trade-offs with increasing production? Could the present industry be doubled and still fall within criteria for acceptable environmental change, while providing considerable greater economic benefits?[1].

Secondly, how convertible are the figures, from one area to another (what are the variations in the productivity and capacity of these environments, such as coastal wetlands, or marine ecosystems?) and between different components of support to the system (how does $1km^2$ of mangrove equate with $1km^2$ sea area?): the area of support per unit of production in a specific system will vary greatly with the natural productivity (for inputs), or assimilative capacity (for processing outputs), of the environment in question. In the above examples, the fact that many fisheries of the world are being exploited at an unsustainable level implies that with declining yields, the actual ecosystem support area required per unit output may increase. There may also be a difference in the support area calculated from a theoretical analysis of the marine ecosystem, and what is actually produced: by demonstrating support area from renewable resources, this does not indicate whether these systems are being sustainable managed.

Finally the comparison of total ecosystem support area for different systems may not reveal important differences, such as the comparative reliance on fossil fuels and renewable resources.

9.3.2 Applications to sustainability analysis

Scope

EFA as a method of technology assessment is primarily focused on the environmental aspects of development, and can be applied to both assimilative capacities and resource use components. The focus is therefore potentially wider than conventional EIA, which tends to concentrate on the outputs and site requirements of the system in question. As it incorporates both renewable and (allowance for) non renewable resource use, the scope

[1] this problem was discussed in Chapter 5 in relation to impact models for a trout farming system.

of the analysis is wider than both industrial and ecological energy approaches discussed in Chapter 6: in some respects it can be seen as a potential method by which these approaches can be presented together with aspects of the EIA. It does not address issues concerned with the social or economic spheres of sustainability assessment.

Scale

EFA appears to be an approach which could be of value in assessing technologies at a local or national policy level, as discussed above. The application of energy analysis techniques discussed in Chapter 6 appear to be more appropriate at a sectoral and policy level: here EFA, including energy analysis, may contribute to the understanding of the extent of a technology's dependence on ecosystem and non renewable resources beyond the local system boundaries. It is not likely to be significant at the firm level, except to the extent that the scale of the operation is matched with certain aspects of local resources, and in particular assimilative capacities for wastes: a component of which would be represented in the process of EIA above.

Participation

As these approaches are not directly concerned with the social aspects of development, and are involved in quantitative systems analysis, there is limited scope for public participation in the process.

Transparency

A claim made by proponents of EFA is its presentation of easily visualised measures of resource requirements of specific technologies: as such it may represent a useful contribution in the communication of specialist information to other stakeholders. However, as with any approach in which there is a large degree of generalisation and uncertainty, unless the analysis builds in some element of sensitivity testing, and boundaries for different apparent levels of acceptability, the information presented is potentially misleading. As suggested above, the total 'footprint' of an activity reveals little of the nature of the resource inputs, and the sustainability of source.

Practicability

Meaningful EFA relies on the availability and reliability of information on the environmental and resource systems associated with the development or technology. Thus its use is constrained by those factors constraining the methodologies from which input data is derived. As an approach to data presentation, this process is relatively simple. At the level of the firm, or local development, this could assist in identifying, for example, assimilative areas required per unit production area, as proposed by Larson et al. (1994). At a sectoral level, it could also be applied to other aspects of resource use.

Cost

The cost of applying this approach to available data will be relatively small, but the value of the output will depend on the quality of the information used. Where information is lacking, the cost, as for any assessment of natural systems, will be high.

Overview

The claims for EFA as a novel approach could be questioned: the concept of 'ghost land' has been around since the 1970s (Edwardson, 1977a, Pimentel and Pimentel, 1979). The method here does, however, widen the boundaries to some extent by considering all aspects of ecosystem support. As a framework, and conceptual approach to bringing together information from a range of different assessment procedures, this may provide a useful tool in certain circumstances. It may also offer a useful means to present this information in a more unified and visual manner, and as an educational concept which illustrates the ecosystem dependency of production processes and human activities. In general, a smaller 'footprint' per unit output for a particular production process is suggestive of greater ecological efficiency and may therefore indicate potentially greater sustainability in those terms.

In its simplicity, however, there is potential for misleading or even wrong interpretations of sustainability perspectives. It is not an approach which could be extended to cover all aspects of sustainability assessment.

9.4 Product Life cycle assessment

LCA has been defined by Assies (1992; in SETAC, 1992) as "studies to analyse and assess the environmental impact of a material, product or product group over the entire life cycle". He points out that the above definition is intentionally open as LCA "covers a wide range of studies with large differences which, for the time being, give rise to much confusion of tongues between practitioners"

One of these more specific definitions is that of SETAC (1991) which presents LCA as "an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact ..... on the environment, and to evaluate and implement opportunities to effect environmental improvements" This encompasses "extraction and processing of raw materials, manufacturing, transportation and distribution, use/reuse/maintenance, recycling and final disposal."

LCA has its origins in the 1960s and '70s, and is essentially developed from methodologies for the analysis of both environmental impacts and resource use (in particular industrial energy) of the production processes which arose at that time. This collection of procedures is interesting in that their use was initially developed for internal corporate decision making, but has since (primarily post 1990) extended to the domain of pubic debate and public policy. This is largely due to the use of "green" marketing claims by producers, and the need to substantiate product life cycles for eco-labelling schemes and packaging laws. In this sense the origins of LCA may differ from EIA and CBA, the latter approaches having been developed in response to policy oriented goals which required evaluation of processes to represent interests beyond those of the company or investor.

Four broad properties of LCA which distinguish between the wide range of methods are as follows (based on SETAC, 1992):

1 Scope: issues that are taken into account, ranging from a single issue such as energy analysis to systems (developed in Germany) for assessment of environmental, economic and social issues, including health and safety aspects.

2 Structure: sections in the structure of LCA can comprise inventory, classification and evaluation, as means to achieve the defined goal (eg internal or external use, scope of study)

3 Types of information: qualitative, semi-quantitative and quantitative approaches.

4 Users: tailored for public sector or private decision making.

Essentially LCA is a systems approach which aims to produce a basis for assessment of impacts and to evaluate these with regard to a pre-defined goal, (valuation and improvement analysis) (Heintz and Baisee, 1992). Depending on the scope, the analysis of connections between the process and the wider environmental, economic and social systems, draws on approaches of environmental assessment, energy analysis and economic and social assessment tools (eg CBA, SCBA, SIA). As such many of the problems with these methodologies, discussed above, will also apply to LCA.

There appears to be no available literature of LCA yet being applied to aquaculture production systems: these are generally small, single product activities, while LCA has been developed to deal with large scale manufacturing industry. The principles, however, could be applied to any process. In fish farming, this could contribute to the development of management practice to reduce the impacts at a range of levels, by focusing attention of operators on elements of the system or practice which might be modified. In the context of increasing pressures for product quality assurance, and at times local concern over aspects such as amenity impacts, such assessment could be of benefit to both operators and the wider public. In the case of the Scottish salmon industry, although not formally applying LCA, these principles are to some extent already being applied. While LCA, as a framework for problem identification and solving, may have something to offer the sustainability assessment process, the data requirements involve the use of other approaches discussed here, thus the analysis, in terms of the criteria applied, will be determined by methods selected. This approach will therefore not be investigated further in this analysis.

Chapter 10 Farming systems and participatory appraisal methods

10.1 Introduction

The case study in Chapter 7 considered a project aimed at development of small scale rural aquaculture, with the broad, albeit implicit objectives of stimulating rural economic development, and improving nutritional welfare through the provision of animal protein. Institutional and management failures were implicated in the lack of success of the project, but the basic project concept and process was also questioned in its 'top down' approach, and lack of assessment of the social, cultural and institutional context of the proposed development. In many respects the project represented a typical development intervention. Thus Lele (1975, in Oasa, 1985), commenting on projects targeted on the rural poor in Africa, observed that "on the whole (these) have been less than fully effective in making the development of the low income sector self sustaining", due to "inadequate knowledge of the socio-cultural and institutional settings in which projects were implemented"

The origin of this approach to development assistance has been attributed by DeWalt (1985) to the "commodity and disciplinary focused research and concomitant simplification and industrialisation of production on farms in the developed countries (which has) .. led to greater and greater emphasis on smaller and smaller parts of agricultural systems". The increasing recognition of the failures of such interventions led to the evolution of a range of 'farmer oriented' approaches to rural agricultural development. Farming Systems approaches to research and development (FSR&D) in less developed countries (LDCs) were developed in the late 1970s and 1980s, and included tools for interdisciplinary and rapid appraisals (RRA). These were, however, still generally run by external specialists, and were thus followed in the late 1980s and early 1990s by more participative methods (Chambers, 1983; Chambers et al., 1989).

The objectives of this chapter are:

- to consider the broad features in turn, of FSR&D and participative approaches.
- discuss their relevance and application to aquaculture systems and developments.
- assess these in the context of the criteria for sustainability assessment

10.2 Farming systems research and development

Shaner et al. (1982) defined farming systems research and development (FSR&D) as: "an approach to agricultural research and development that:

- views the whole farm as a system.
- focuses on (1) the inter-dependencies between the components under the control of the farm household and (2) how these components interact with the physical, biological, and socioeconomic factors not under the households control"

They further emphasise that the process is "farmer based, starting with learning about their environment, resources, methods of production, problems and opportunities, aspirations, and how they react to change"; it is also interdisciplinary, complements existing research and development activities, is iterative, dynamic and responsive to society.

In practical terms, the process has been described in four stages (Gilbert et al, 1980, in Oasa, 1985):

- the descriptive or diagnostic stage, in which farm constraints and potentials are identified.
- the design stage, in which strategies are developed based on the above.
- the testing stage, in which promising strategies are examined under farm conditions, in two parts; the first involving both researcher and farmer, the second involving total control by the farmer.
- the extension stage in which strategies deemed successful are implemented.

In practice, FSR&D has not lived up to the full expectations of the holistic, responsive and adaptive approach described above, and successes have been limited to quite small areas (Tripp, 1989). This has been attributed to a number of factors as follows:

Over simplistic treatment of "social issues"

This criticism can be raised at a number of levels. In many cases the social dimension of FSR has involved socio-economic surveys (usually by agricultural economists) solely at the first stage of development, rather than being fully integrated into the process (Oasa, 1985). Tripp (1985) called for the involvement of anthropologists through the whole process of FSR, pointing out that the "complexity of reality severely limits the ability of anthropologists or economists to devise models that accurately predict farmers' behaviours in relation to new technologies".

There has also been a tendency to examine separate physical, economic and social components without an appreciation of the interrelated nature and dynamic interaction of these parts (Scoones and Thompson, 1993). Farmers have also been assumed to be apolitical and asocial, the household representing the 'unit of analysis'. According to Harrison (1994b), there has been a "persistent failure to look inside the 'black box' of the household. Joint household interests are assumed, with a benevolent male control....despite the evidence that variation in household relations and composition is such as to make the unit of analysis (the household) of little analytical value."

Problem of interdisciplinary cooperation amongst practitioners.

DeWalt (1985) also noted a degree of professional misunderstanding, and a failure to appreciate different perspectives in FSR between technologists[1] and social scientists. The latter, being used to long term field studies, often came into conflict with the former over the relevance of information collected, and the time required. These problems with conventional methods led to the development of multidisciplinary rapid rural appraisal (RRA) methodologies, which were considered to faster, more economical and more accurate (McCracken et al., 1988; Chambers, 1992).

Problems of transferability of results

The basic premise of the FSR approach is that representative farmers are selected. However, in practice, the great diversity of farmers conditions mean that the output of FSR involving a small number of farmers may not be transferable (Tripp, 1989). The idea that farmers operate within an identifiable knowledge base assumes a uniformity which does not exist (Richards 1993, and Gatter 1993, in Harrison 1994b). As with previous sectoral and technology driven interventions, FSR has also tended to focus on the more visible, better off in rural communities. Further constraints to the wider application of the results of FSR, noted by Chambers (1992), include complexity, unpredictability and uncontrollability of many small scale farming systems.

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[1] referring to specialists in technology of production, and related scientific disciplines.

External factors

Many of the factors which influence farmers' decision making are associated with external forces, leading Little (1985) to conclude that "a strict focus on farm level resources limits the analysis to secondary, rather than primary causes of production changes".

In addition to the above limitations, at a more fundamental level, Oasa (1985) questioned the extent to which farmers are really involved in the shaping of the development process in this approach. He considered that FSR

> "is a change in form but not in content. Its participatory aspect, upon which claims to novelty are based, amounts to nothing more than a change in the 'tops' form to get to the 'bottom'[1]. Despite the benefits of new methodologies developed as a result of the FS philosophy, such as rapid rural appraisal techniques (RRA), the information gathering processes have remained essentially extractive, and the approach to (technological) introductions prescriptive".

It is this last observation which led to efforts to develop more participative approaches to rural appraisal (PRA), research and extension, evolving from RRA process (Chambers, 1992).

10.3 Participative Approaches (Appraisal, Research and Extension)

Arising largely in the context of rural development in LDCs, participation is now a central component in the language of sustainable development, and has been highlighted in the principles of 'Agenda 21' of the Rio summit (UNCED, 1992). The concept applies to both the involvement of local people in the identification of issues and the development of resource management regimes, and in the process of consensus building between local people, technical and development specialists, planners and policy makers, at all levels of organisational structures.

Participative rural appraisal (PRA) has its roots in the RRA techniques developed during the late 1970s and 1980s. Although RRA techniques were considered to be an

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[1] ie maintaining the 'top down' approach for which conventional development interventions were criticised.

improvement on more traditional questionnaire based surveys, they were often essentially extractive, retaining analysis and decisions with the external agents. It was through the involvement of rural people themselves, as information gatherers, that PRA approaches evolved. Chambers (1992), in discussing rural appraisal techniques, expressed a caveat before attempting to apply static labels to approaches or methodologies which represent "combinations and fluxes of activities which are far from static, and take different forms in different places". Many of the principles of RRA are shared by PRA; the approaches are within a continuum, with PRA transferring much of the action from 'outsiders' to 'insiders'. On this basis he goes on to consider

> "RRA as a form of data collection by outsiders (investigators) who then take it away and analyse it; and PRA as more participatory, meaning that outsiders are convenors, catalysts and facilitators to enable people to undertake and share their own investigations and analysis.. and often to plan and take action".

There is a growing literature documenting specific applications of RRA and PRA methods (Chambers et al., 1989; Scoons and Thompson, 1994; IIED, 1994), the broad principles of which are presented by Chambers (1992) (outlined in Table 10.1). While providing an overview, he warns against too much emphasis on specific methodologies, considering that participative approaches are more about personal behaviour, rather than epistemological: learning through doing, critical awareness, adaptability and informed improvisation. Therefore although basic training in methods is required (and manuals may provide guidelines), this should be structured to develop the personal skills of development workers, with a focus on principles of approach, rather than method. In illustrating this point, Chambers comments on

> "the largest and heaviest manual in India (in mid 1992)...The reader opens it to find boldly printed on the first page:
>
> USE YOUR OWN BEST JUDGEMENT AT ALL TIMES
>
> The other pages are all blank"

The point could be applied to many assessment approaches: while some may call for more tightly specified methodologies, non can do more than the information available. Too much faith in highly defined methods at the expense of critical appraisal and innovation can seriously limit relevance to the decision making process.

Table 10.1 Principles of RRA and PRA

Principles Shared by RRA and PRA

- a reversal of learning, to learn from rural people, directly, on the site, and face-to-face, gaining from local physical, technical and social knowledge.

- learning rapidly and progressively, with conscious exploration, flexible use of methods, opportunism, improvisation, iteration and crosschecking, not following a blueprint programme but being adaptable in the learning process.

- offsetting biases, especially those of rural 'development tourism'[1], by being relaxed, not rushed, listening not lecturing, probing instead of passing on to the next topic, being unimposing instead of important, seeking out poorer people and women, learning their concerns and priorities.

- optimising trade-offs, relating the cost of learning to the useful truth of information, with trade-offs between quantity, relevance, accuracy and timeliness. This includes the principles of optimal ignorance- knowing what it is not worth knowing, and of appropriate imprecision- not measuring more than is needed.

- triangulation, by use of a range of methods to crosscheck information.

- seeking diversity in information, rather than averages, maximising the diversity and richness of information, deliberately looking for contradictions, anomalies and differentness.

Additional principles stressed in PRA

- facilitating, by initiating the process of appraisal carried out by rural people themselves.

- self-critical awareness and responsibility: the facilitator continuously evaluates their own behaviour, treating error as opportunity to learn, trying to do better. ie personal responsibility rather than investing this in a rigid method or set of rules.

- sharing of information and ideas between rural people, other facilitators, organisations etc.

(Adapted from Chambers, 1992)

[1] Chambers (1983), used this term to refer to the brief rural visit of urban based professionals involved in rural development, and discussed biases in information and understanding which can result. These can include spacial (farmers visited usually near- urban, tarmac and roadside); Project bias (usually directed to where something is being done); person bias (who they meet; elites; males; adopters); dry season, diplomatic and professional bias.

Chambers (1992) also considers a number of other pitfalls with RRA and PRA methods, which could also be applied in general principle to other appraisal techniques. These include faddism (sticking RRA and PRA labels to bad practice), rushing (in that while rapid, in comparison to traditional approaches to learning about rural communities, they should be relaxed), ruts (forming of habits and routines, losing the innovatory component of application of the basic principles) and rejection (the possibility that "experts" will feel professionally marginalised by the development of these approaches).
In anticipating the benefits of such approaches, Chambers (1992) suggests that

> "the challenge now is for outsider professionals to further develop and disseminate approaches and methods to help farmers do their own analysis and make their own needs and priorities known to scientists. If such efforts continue to be successful, the implications for activities, procedures, training, rewards and institutional cultures in agricultural education, research and extension will be little short of revolutionary". However, he later adds, in advice to potential practitioners, "PRA is what we make of it. It is a potential, not a panacea.."

It is too early to say to whether and how this might affect most development intervention. Participation is certainly a fashionable concept in sustainability, and represents the process by which the cultural capital element of the '3 capitals' resource model is drawn into the development process: it is considered important in the development of acceptable trade-offs in resource allocation, development of sustainable resource management regimes, and in providing mechanisms for reducing inequity. It may also be seen to carry quality of life concepts, in terms of feelings of belonging and 'empowerment' within and of rural communities. However, earlier comments about farming systems research could perhaps be applicable to PRA today. DeWalt (1985) considered that:

> "FSR provides an important perspective on development. However, like other 'buzz words' and phrases that have cropped up in the halls of aid agencies and banks, FSR is likely to go through a predictable evolutionary history. At first there is a kind of euphoric adoption of the term by everyone except for hardened, cynical old timers. The term is thrown around everywhere, particularly in loan and grant requests, technical reports and academic publications. FSR is already

into the second stage of its evolutionary history; in this stage, people begin to look critically at the concept, debate whether it is really all that different from past approaches, and discuss whether it can really have any impact"

Participation might equally be loaded with expectations, but, like any other tool, it will be subject to limitations in its application. The popular view is of a transfer of power from outsiders (specialists, policy makers) to local people, a process of ownership and empowerment. However, this is an oversimplistic view of its function in developing more sustainable resource use behaviours. Scoons and Thompson (1993) point out that all stakeholders bring their own views and preconceptions, and that views of local people do not necessarily reflect the needs of more sustainable development, or even their longer term 'best interests'. Thus, in Malawi, Stewart (1993a) noted that farmers' expressed needs for credit and material assistance in developing rural fish farming activities would not be appropriate (or feasible) means to develop a viable fish farming sector, functioning without ongoing assistance from external agencies, nor, potentially, might it have been sustainable from a resource use perspective (in terms of allocation of public funds). The perceptions of farmers adopting fish farming in this case appeared to be associated with a history of dependency which may have actually hindered the potential for development of local innovation and enterprise.

Similar potential conflicts have been identified by LGMB (1994) in developing participative approaches to implementing Local 'Agenda 21' initiatives in the UK: warnings are given of the potential divergence between issues of importance identified by local people (which tend to be short term and local in focus), and those longer term, wider scale issues of potential relevance to sustainability.

Therefore, just as 'top down' processes dominated by 'specialists' and 'outsiders' may be inadequate in seeking solutions or answers to development needs, the notion of populist 'participation' to elicit local peoples knowledge and involvement may be equally suspect. Commenting on the reductionist and simplistic view of both these approaches, Scoons and Thompson (1993) suggest that "there is no single reality, but multiple, contested realities, each with potentially conflicting social and normative interests and diverse and discontinuous configurations of knowledge", and that a more holistic perspective may be needed.

In conclusion, it appears that the application of participatory principles to sustainability assessment is less about methodologies, and more about the way the process is structured, and the outlook of those involved in specifying and implementing the process. Participation can be seen as a means where potentially conflicting views and values of different stakeholders can be better incorporated into assessment and decision making. However, it is also about exchange and learning, and interaction in which all stakeholders may learn from different views, reevaluate their own thinking and values, potentially allowing a more complete and balanced understanding in the process of sustainability trade-offs.

10.4 Farming systems and participative approaches in aquaculture development

Historically, aquaculture developed as part of integrated farming systems in Asia and Central Europe, where fish production relied on resources shared and recycled locally with animal and crop production, where inputs of one activity were tied in with outputs of another. This contrasts with recent development trends, as in other food production systems, characterised by increased separation and specialisation, intensification, and the development of industrialised monocultures (Little and Muir, 1987), with a change in emphasis from efficiency-increasing to throughput-increasing development.

The search for sustainability suggests that the former modes of production were more sustainable, at least in their patterns of resource use, and has led to attempts to recreate such integration, both at the level of the small scale rural farming enterprise, and in the context of local integration of larger scale production processes under the concept of "ecological engineering" (Mitsch and Jorgensen, 1989). This involves not only the technical capacity for integration of various activities, but also the development of appropriate management systems, at a range of levels, in the context of the cultural and social environment in which they occur.

Some of the most ecologically efficient integrated aquaculture systems of recent years developed in southern China, in the three decades following 1949 (Ruddle and Zong, 1988). This was a period when the system of production was organised according to socialist collective principles, with emphasis on maximising resource use efficiency. Since the early 1980s, rural reform has re-introduced the effect of market forces, and producers are now looking beyond their farming system for inputs, including manufactured feeds. While this can increase outputs, and potential financial returns, the increasing flow-through represents a decrease in ecological efficiency (increasing the ecological footprint described above).

It is significant that it was policy framework which was largely instrumental in developing ecological efficiency. This is not to advocate the policies concerned, but to acknowledge the importance of the policy context for the pattern of development. Promotion of ecologically efficient and "sustainable" aquaculture systems in an economic and social environment which favour, for example, intensive flow through production, is not likely to stimulate significant change.

The potential advantages of integrated aquaculture in resource limited farming systems has stimulated research and development to improve the many traditional systems (in Asia) and to introduce this approach in regions with little history of aquaculture (Africa) (ICLARM/GTZ, 1991). One such example was presented earlier, where the integrated model of aquaculture development assumed that pond inputs would be derived from local farming operations. However, in this case, the approach was to deliver a single 'technological package' to farmers, rather than developing suitable approaches with farmers in the context of their knowledge and other farming activities. The failure to take the social and institutional contexts into account in such projects led to the introduction of FSR&D and PRA for aquaculture development in Africa.

While fish have been part of some farming systems for thousands of years, the concepts of farming systems have come rather late to aquaculture development. In fact, the very existence of aquaculture as a separate sector, commonly assisted through organisations associated with fisheries development, has been a principal constraint for an integrated farming systems approach in development assistance. Molnar et al (1987) discussed the application of FSR to aquaculture in regions to which this is a new technology with reference to Africa. The FS approach has also been a central philosophy of two major rural aquaculture research programmes in Southern Africa since the appraisal mission described in the case study earlier; a project in Malawi run by ICLARM (ICLARM/GTZ, 1991), and the FAO administered ALCOM regional project (Aquaculture for Local Community Development, ALCOM, 1987). Both were established with the aim of "methodology development", to address the need for better understanding of the socio-cultural and socio-economic motivations behind small scale farmers' decisions to adopt aquaculture: a perceived weakness of many previous development interventions (UNDP/NMDC/FAO, 1987)

However, although these were an advance on previous approaches, they have both been criticised on aspects which are characteristic of the problems of FRS and participatory approaches as discussed earlier:

- in addressing social and cultural dimensions of rural farming systems, these projects both treat the household essentially as a "black box" (Harrison 1994b).

- the information obtained, and the approaches developed, do not appear to have resulted in a more widely applicable development approach.

The ICLARM project in Malawi involved a small and select number of (mostly male) farmers. Outputs included studies of resource flows in the integrated aquaculture system, developments in farmer participatory methods for research and extension, and claims for aquaculture as "a route to sustainable farming systems" (Lightfoot, 1990). However, there has been little evidence of these methodologies being translated into wider action to successfully introduce aquaculture as a component of rural farming systems (Stewart, 1993a). Neither of these projects, which focused on FSR and participatory methodologies at the farm level, and involved a small body of highly trained national and expatriate specialists, addressed the problems of implementing "methodologies" through under-resourced, poorly trained and under-motivated field extension workers.

These projects have attempted something different in aquaculture, but have come up against the problems of complexity associated with the social and cultural dimensions of both farming households and communities, and have also failed to address some of the greatest constraints which lie in the institutional aspects of support to these communities. These criticisms could equally well be applied to development efforts in most other sectors in the region. They also highlight the fundamental importance of the higher level institutional systems when considering the needs for the development and implementation of more sustainable activities and resource management at local levels.

Departing from the LDC, rural development focus, there are also a number of examples of integration for improved ecological efficiency in industrial aquaculture, and also in resource management systems at local and regional levels. At the level of the firm, there is growing interest in reducing waste impacts of intensive nutrient enriching systems such as salmon and shrimp production, by integrating these with nutrient removing forms of aquaculture, such as shellfish and algae (Folke and Kautsky, 1992; Anon, 1994). This potentially reduces problems of deteriorating water quality, while also providing additional marketable produce.

Beyond the firm, there is growing interest in the use of aquaculture technologies to reduce problems of aquatic ecosystem enrichment while producing valuable products. A well documented example of this is in India, where waste water from Calcutta is being used to fertilise fish ponds, resulting in production of about 13000 tpa, the processing of about 0.5 million m^3 waste water per day, and direct employment of over 1000 people. While this might be seen to offer considerable potential for other areas, Muir et al., (1994) have noted that "the characteristics of this system are highly specialised, and related as much to geographical, historical and social accident as to any idealised development approach". Inui et al (1992) considered similar concepts in Japan, in the form of coastal aquaculture of seaweeds, filter feeding and mud feeding organisms. They emphasise, however, the need for suitable institutional structures to stimulate and coordinate any such developments, both at the level of government, and local communities. It is clear that more integrated development approaches depend not just on technical prospects, and that social aspects are likely to be a key factor. Thus participatory approaches may well contribute to the realisation of such potential.

10.5 Applications of systems and participatory approaches to assessing sustainability

In considering the potential for these approaches in sustainability assessment, it must be noted that there a less clear cut division between their use for appraisal and for development, as the methodologies themselves embrace the concept of ongoing assessment and feedback, as necessary, in the development process. The process is as much about assessing ongoing contributions to the development process, as it is for assessing the potential for sustainability only at the appraisal stage.

Scale of application

Farming systems and participative approaches appear to offer inputs to sustainability assessment at a range of levels. Examples of application range from aquaculture development in small scale farming enterprises, through to the development of larger scale, locally integrated resource use patterns, in which discrete aquaculture enterprises may complement other activities and sources of impact. The approaches used will vary with scale and context, and will not necessarily be appropriate at all levels in all cases.

The role of participation has tended to focus at the level of the rural farming system, and elsewhere as a means to involve the public in development debate, and in 'community based' projects. While important, this may neglect the potential role of improved communication, or participation, at higher levels, between specialists and institutions, in formulating strategic approaches and policies aimed at the development of more sustainable resource management regimes.

Scope

The philosophy of FS aims to cover aspects of all three sustainability spheres, providing a framework on which specific methodologies can be applied. Similarly, participatory approaches may be contained within a wide range of assessment and valuation methods, in particular those focused on social dimensions (social impact, and social cost benefit analysis).

Practicability

The principle of these approaches could be seen as relatively simple, and in some respects might be central to genuinely sustainable activities. However, the change in attitudes required for all levels of the development process may be a major constraint. The incorporation of systems approaches to development requires interdisciplinary focus in both science and planning, implying the need for improved participation at these levels. The process of integration of a wide range of views (including specialist and lay people), and the invoking of genuine participation at all levels will not be easily or quickly achievable. Elements of these approaches may also threaten existing power structures and may encounter considerable resistance. These approaches may therefore be seen as a long term goal for improving assessment, which would need to start with their introduction into education and training at all levels. The limitations to wider participation in certain elements of assessment and decision making must also be recognised. There are likely to be certain elements of the scientific process which will remain within the realms of specialist knowledge, and certain elements of decision making, at higher strategic levels, in which wider public participation will not necessarily contribute to the pursuit of sustainability objectives: the participatory role here can be better seen as a need for improved communication of the reasons of certain decisions, rather than a direct say in those processes.

Participation

This is clearly the central philosophy of these approaches. As noted earlier, however, only the notion of participation may be involved as a guise for what is essentially extractive information gathering. In invoking participation as part of sustainability assessment, there is a need to consider carefully the way in which this is to be achieved, and what value it contributes to the process.

Transparency

These processes themselves offer the transparency, in that their application should aim to incorporate a wide range of system elements, and stakeholder views. The output of appraisals in which these approaches are applied should therefore be capable of presenting information which explicitly reveals a range of different views. As with other methods, however, there is the potential for bad practice to confuse or mask the issues.

Cost

In the context of rural development programmes, these methods have been criticised for heavy reliance on outside expertise, and limited results at the wider development level, implying high costs for small benefits. This is partly due to lack of the integration into the wider systems of support to the rural sector: as they represent a change in focus and approach to development, there is no reason why, once established, they should be more costly than present systems (ie when outside specialists are no longer required). In this respect the costs of such change would be associated in the investments in education and training required. Similarly, in developed countries, systems and participatory approaches, as means to integrate development planning, improving communication and generating informed debate, need not necessarily represent a major cost, but would require a change in practice.

Overview

Given that sustainability can be viewed as a systems problem, in which participation (at a range of levels, both public and professional) is recognised as a critical feature in attempts to make more sustainable resource allocation decisions, the principles of these approaches are likely to be applicable to a wide range of assessment approaches and levels. The application of systems approaches implies assessment in context, and thus represents fundamental aspects of sustainability. Participation, however, can be interpreted in a number of ways, and in the populist view, as public say in local development decisions, will not necessarily contribute to sustainability objectives.

At the local level, it could be concluded participatory approaches to development of sustainable aquaculture has a greater role in LDCs: here there is likely to be a greater gap between the perspectives of those assisting such development efforts and rural people. Developing appropriate technology, within the capacity of local resources, and existing social and cultural structures for resource use and control, clearly requires local solutions, which will require local involvement in the evolution of more sustainable development. As noted above, however, the activities of higher level societal structure and decision making will also have a major influence on the extent to which such local focus will lead to real change. For larger scale developments, potential impacts on subsistence level activities may also be usefully assessed by participative methods.

In developed countries, it is less a question of appropriate technology, than the wider values to be considered in the development of a specific technology in specific location. Thus local level participation here is more likely to be associated with potentially conflicting aspects such as jobs versus environmental impacts (wildlife, recreational and amenity value). Public participation does not mean everyone gets what they want, but that they may have an opportunity for their views to be considered in the assessment and decision making process.

At higher levels, in all situations, participation between different specialist and administrative systems can be seen as an important aspect of assessing sustainability.

Beyond the process of achieving learning, communication and informed trade-offs, participation, as a socially rewarding, non material process, may also be seen as contributing to quality of life, representing a positive social perspective for sustainability.

Chapter 11 A strategic analysis of methods

11.1 Introduction

The objective here is to analyse in strategic terms the broad features of selected methodologies in the context of sustainability for aquaculture development. The conflicts between the need for technical, objective oriented specialisation, and the needs for a widely based, participative process, are discussed, followed by a summary of features of a range of methods, and a discussion in terms of the level at which they might be applied (ie firm, local and national).

Before considering how the above analyses might be brought together on a comparative strategic basis, a number of thematic points can be brought out from the previous chapters:

- none of the methodologies examined are sufficiently comprehensive to address the needs of sustainability assessment as specified in the criteria developed for the analysis. This suggests that the process will require a combination of appropriate methods selected to meet the needs of specific development situations.

- all the methods considered have, in principle, the potential to contribute to the process of assessment, ranging from specific views and aspects of the system, to more general systems and participatory approaches.

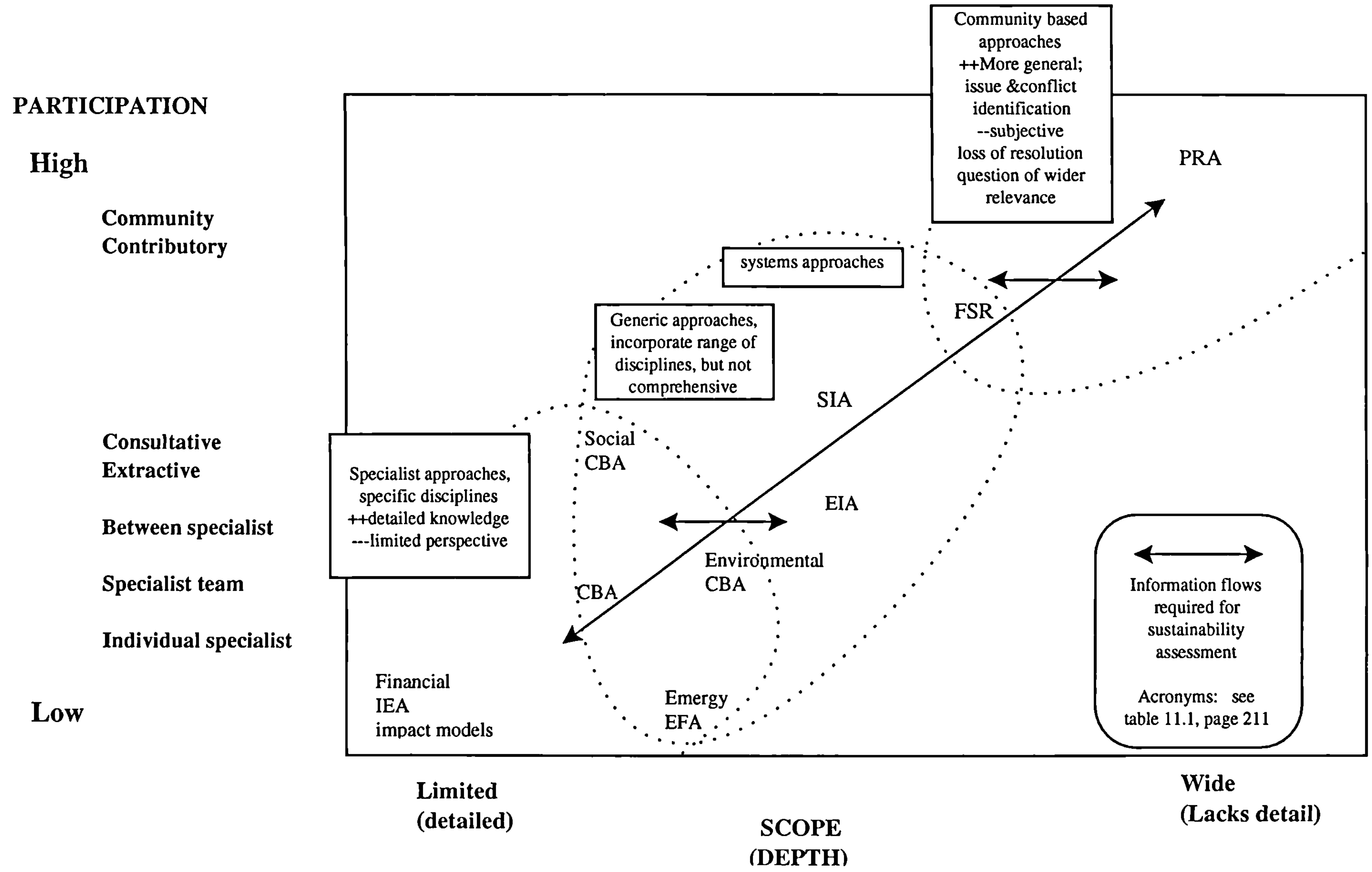
- all methods have limitations. These have been considered in terms of the specific objectives and characteristics of the methods in theory, and in the way they are often applied in practice. Lack of information, variability and uncertainty are constraints faced by all methods. The potential introduction of bias of the appraiser is also common, to varying degrees.

11.2 Conflicts between specialisation, scope and stakeholder involvement

A significant problem facing sustainability assessment is achieving a balance between specialist, objective-oriented inputs dealing with specific aspects, and broadly based processes which incorporate both a wide range of specialist issues, and views of the range of stakeholders. Much of the criticism directed at the output of specialist studies is that they are too narrow, and often do not take sufficient account of other aspects of the system. This may be largely a result of the focus of academic disciplines from which they arise, and the reductionist approach necessary to understanding key aspects within the complexities of natural and social systems. The argument in support of such reductionism is that it is still the best available means to increasing knowledge on components of the system. However, with increasing specialisation, the information generated becomes less accessible to other stakeholders, both across disciplinary boundaries, and to decision makers and the wider public. At the disciplinary level, this has been particularly evident in the poor communication between the natural and social sciences, and has stimulated efforts to develop more integrated, systems based approaches, such as those identified, but by no means widely practiced, in the field of ecological economics.

A generalised comparison of the relative position of different types of appraisal method reviewed, in terms of scope and level of participation, is presented in Figure 11.1. As discussed earlier, participation can refer to communication at an interdisciplinary level, and between specialists and wider interest groups (eg planners, policy makers, community groups and the wider public). It can also refer to the active involvement of non specialists in setting agendas and prioritising issues of importance. A general characteristic is that as the level of the participation increases, so does the potential scope of issues covered. However, this may easily be accompanied by a loss of resolution on specific aspects of the system: there will therefore remain many aspects of specialist assessment where wider participation is both impractical, and of no constructive value. There is also likely to remain aspects of the science which will not enter the systems of wider public understanding, particularly when dealing with concepts of risk and uncertainty. Furthermore, there is a potential for conflict between priorities set by local perceptions and agendas, those of wider public agendas, or those of more strategic national or global sustainability.

Figure 11.1 Relationship between specialisation, scope and participation in assessment methods



It was suggested that the use of participative appraisal methods at a local level may be of greater value in LDCs (in terms of development of appropriate technology, and in assessing subsistence level activities). In developed economies, the focus of such approaches is more likely to be limited to providing a forum for local views to enter the assessment and decision making process, and also associated with increase local understanding of elements of specialist assessment, and the rationale for higher level development agendas.

To conclude, the process of sustainability assessment is likely to require a range of methods from highly specialised and defined studies, to the general and wide ranging. There will therefore need to be some form of over-riding decision system to allow choice across this spectrum, while providing a communicable rationale to participants.

11.3 Overview of features and level of application.

It was suggested earlier (Chapter 4) that part of the assessment process may be to select the appropriate methods, and levels of investigation, based on the perceived needs of a specific circumstance. It is clearly not possible, nor necessarily desirable, to try to apply all approaches in all situations, nor to suggest specific combinations of methods which might be applied to aquaculture systems. However, the analyses of methods earlier provides indications of the likely relevance of different methods at different systems levels. Table 11.1 summarises broad features of these analyses, and applies a simple ranking of methods according to:

- the specialist fields from which they have been developed (simplified in terms of the three main categories of economic, social and environmental systems, which correspond, in general terms, to the three sustainability objective systems), and the scope, in terms of the extent to which they incorporate aspects of other systems.

- the type of measures and valuation systems applied, include monetary, quantitative (non monetary) and qualitative.

Table 11.1a Overview of assessment methods

Method	Scope / Origins			Type of measure	Practicality, cost and scale of application		
	Economic	Social	Environment (Resource)		Firm see 11.1b	Project (+local policy)	Policy (eg.national)
Financial	+++			££	+++	+++	+++
CBA	+++	++	+	££	+	++	+++
SCBA	+++	++	+	££	+	++	+++
EIA	+	+	+++	QL/QT/£	+	++	+++
SIA	+	+++	+	QL/£	+	++	+++
EA	+	+	+++	QT		+	+++
EFA	+	+	+++	QT		+	+++
PRA	+	+++	+	QL/QT	+	+++	+
PA	"	"	"	" "	+	+++	+++
	Integrated approaches						
FSR	+++	+++	+++	QT/QL		+++	++
LCA*	+	+	+++	QT/(QL?)	+++	+++	+++

* can comprise a range of other approaches: EIA, EA, sometimes SIA/SCBA

Table 11.1b Firm level assessment

Method	Commercial	Rural, semi--subsistence
Financial	+++	+
LCA	+++	
PRA	+	+++
FSR	+?	+++

Acronyms:
CBA, SCBA: Cost Benefit and Social Cost Benefit Analysis.
EIA and SIA: Environmental and Social Impact Assessment
PRA; Participative Rural Appraisal- here local/ public level
PA; Participative Appraisal- here professional level
FSR: Farming Systems Research
EA/ EFA: Energy / Ecological Footprint Analysis
LCA: Life Cycle Assessment
QT/QL/£ Quantitative/Qualitative/Monetary measures

- the practicality and cost of methods as related to different scales of application. This is based on three target levels; the firm, local policy and projects, and national policy levels.

Not included here is the criterion of transparency, related to the capacity for information generated to explicitly reveal the value judgements and assumptions, and communicate these to a range of stakeholders: it was apparent that all methods can have varying degrees of transparency, depending on how they are applied, to whom they are addressed, and how the information is presented. It was also noted that some methods are potentially transparent, but limited in scope (eg CBA), some are inherently complex, thus simple and 'transparent' outputs may be misleading (eg EFA).

Having accepted that sustainability assessment must take account of a wide range of potential features, and that a range of methods might be applied to these features, the objective now is to consider their likely applicability at different systems levels.

A general point was that financial and economic approaches will represent a fundamental component of the process of assessment at all levels. The extent to which boundaries are extended to address other issues will vary with the particular circumstances of the assessment. It can be argued that at the level of the firm, the key criteria will be technical and financial viability. While some local participation in the development decision may be desirable[1], this and other methods of assessment may have a relatively low level of importance. At first sight this may appear to conflict with the rationale that for sustainability of the whole, the concepts must be included in the decision making of all the parts, which come down to activities of individuals and individual firms. While this may be so, the sustainability assessment at the level of the firm only becomes meaningful when set in the context of other activities at the local and higher levels. Furthermore, as most aquaculture developments are relatively small, with relatively limited impacts in the context of other activities, subject to basic safeguards, a wide ranging assessment may not be relevant, or justifiable in terms of costs.

[1] particularly in LDCs, as described above.

The activities of individual firms become more important when specific impacts contribute to exacerbate the impacts of other activities (due to cumulative or threshold effects relating to environmental capacity), or where the firm threatens specific features of the local environment. Sustainability assessment therefore becomes more relevant, and feasible (in relation to the scale of the economic activity it represents), at local and higher levels. One of the objectives of such a process would be to define the relevant issues at appropriate levels, either providing a case-related decision approach, or creating a more general policy and planning framework, based on specified indicators and criteria, on which specific planning decisions can be based. For example, environmental impact modelling, and specification of monitoring requirements, may be required at the level of the firm to fulfil specified information needs of the planning process in a particular location. The costs involved, whether born by the firm, or assumed as a public cost, could in turn be brought into the financial and economic context.

The same rationales apply when moving from the local to the national policy level. At the national level there may be broad issues of relevance to sustainability in which the focus on a specific technology or sector is set in the context of the wider national objectives and policy in other sectors. The higher the level, the greater the economic activity the assessment represents and therefore the greater justification for the cost of implementing such assessments.

11.4 Building on existing methodologies

In seeking an holistic approach to sustainability assessment, a range of existing methodologies have been considered and subject to a structured analysis. The increasing overlap between many available methods was noted, particularly in recent attempts to widen the boundaries of many established approaches. For example, Dalal Clayton (1994) suggests that extending EIA to include CBA and PRA, may be appropriate for sustainability assessment. Similarly, van Pelt (1993) has proposed that Multi-Criteria Analysis, which has arisen from economic approaches, and extends to include elements of EIA and participative methods, can meet these needs[1]. As yet, however, there is little

[1] This involves combinations of methods considered above: thus the results of an analysis of MCA based on the specified criteria applied in this study would depend on the specific approaches incorporated.

evidence of such approaches being applied on a wider scale. Farming systems approaches also have been claimed as integrated enough to meet the need of sustainability assessment, although the limitations encountered in practice are apparent. Current applications of CBA methods, even where attempting to include environmental values, will be limited by the scope and assumptions of the valuation structures applied, and the extent to which the concepts of willingness to pay can identify the real and longer term issues of importance. For these, and energy valuation techniques, there will, in practice, remain elements of the systems which cannot be accounted.

Given that there may be many, equally valid approaches to this problem, depending on the specific circumstances of the assessment, it could be argued that the specific methodology is less important than the question of how well the issues are addressed. All of the methods above appear to have something to offer, but none in its present form appears to be sufficiently broad ranging. However, in seeking a generally applicable approach, in the context of aquaculture as a natural resource based sector, it appears that the broad concepts of EIA (rather than existing practice) may best suit the needs of an extended and holistic analysis required for assessing sustainability. This view is based on the results of the earlier analysis of EIA, and relates to:

- the concept of a framework or approach which can represent both a planning and management tool, in which feedback and identification of potential for technological modification is an important component.

- the fact that this framework can, in theory, be applied at a range of levels, and be adapted to incorporate any number of views, methods and valuation systems.

The method proposed in the final section of this study represents a soft systems framework for developing the assessment process, based on concepts similar to those of the EIA process.

SECTION 4

AN APPROACH FOR ASSESSING SUSTAINABILITY OF AQUACULTURE DEVELOPMENT

Chapter 12 A soft systems framework for sustainability assessment

12.1 Introduction

The objective of this section is to propose and demonstrate a 'soft systems' framework for sustainability assessments for aquaculture, based on the various themes and issues discussed in the previous sections. It is thus not intended as a blueprint, but as a logical means of bringing together the wide range of issues and problems involved. This is applied to a range of aquaculture systems, although as a desk study, it is a simplification of the process in practice.

Based on the analyses presented earlier, the context of the assessment process must be considered in the light of the following points:

Limited definitions

- Though basic criteria and conditions can be identified, sustainability is an imprecise concept and goal, which, strictly speaking, will not be fully measurable by any selection of methods. The sustainability literature highlights the problems of forecasting, and the limitations in ability and/or willingness to deal with these in decision making processes. What is needed is a pragmatic approach by which these problems can be acknowledged, while some practical means of initiating a change can be implemented.

- Applied in a more simplistic, and operationally useful manner, sustainability assessment can be interpreted as the process by which features of an activity relating to broad concepts of sustainability can be defined and assessed against alternative options. In this process, indicators relating to these concepts can represent a substitute for clearly defined goals, and can in the longer term be used for validation.

Objectives

- The objective is to make a wide range of information more explicitly available to the decision making process, through which the potential for directing change towards greater sustainability can be identified. This can be seen as a 'soft systems' process, in which the use a range of assessment methodologies, including hard systems approaches, will be required.

Methods

- The specific choice of methods may be less important than the process by which the assessment requirements are defined and implemented, and how the information generated is used.

- Selection of appropriate methods requires definition of context and scale of the assessment, and recognition of hierarchical organisation and control of human and environmental systems. Specific rules for the selection process have been proposed. The broad requirement is to provide an achievable, but suitably comprehensive analysis, in a cost effective manner, presenting results in an understandable form, in which assumptions and value judgements are explicit.

Outputs

- The output of such an appraisal will involve both quantitative and qualitative data. Specific developments or technologies may well display conflicting elements in terms of sustainability features: compromise and trade-offs are likely to be central to the decision making process.

Decision making

- The question of sustainability will therefore depend very much on the extent to which, and the process by which, the relevant issues, indicators, and methods of assessment have been identified; how the value judgements are weighted, and trade-offs made; who is involved in the process, what are their interests, and how these interests relate to the concepts of sustainability, and the interests and views of different stakeholders. The process should therefore seek to develop appropriate levels of participation, particularly in defining relevant issues and providing inputs to decision making. This represents both participation at professional and public levels, the roles of which will vary with the context of the assessment.

- Due to the problems of limited information and uncertainty, value judgements may subsequently prove to be misplaced in terms of sustainability objectives. In this respect, the potential importance of aspects of uncertainty, or risk, and reversibility of particular courses of action, must be considered in making decisions.

- The question of sustainability of an activity in the context of wider ongoing resource management policies can be seen as an evolutionary, or soft systems process. The human system, in which and by which decisions are made, is as much a part of the process as the application of specific appraisal methods. The wider soft systems view does not remove the need for hard decisions to be taken.

Levels of application

- Assessing sustainability at the level of the firm, from the producer's perspective, will, in most cases, be concerned with ongoing commercial viability. However, this does not offer societal perspective. Assessment at this level will only be relevant in the context of existing frameworks of indicators and criteria on which the activity of the firm can be seen in relation to wider systems. To some extent this implies that the proper context for sustainability assessment begins with local resource allocation decisions, moving up to regional and higher levels.

12.2 The assessment process

12.2.1 Introduction

As discussed earlier, it is inappropriate to propose a standard checklist or matrix selected from the very wide range of potential appraisal methods available. What is required is a process by which the assessment might be developed and appropriate methods selected for a specific appraisal. The general elements the process proposed here, consist:

- screening and scoping, in which the need for further analysis is established, and boundaries for analysis identified.
- detailed assessment (selection and application of specific methods).
- presentation of information to the decision making process, with identification of the potential feedbacks and controls, where required.

12.2.2 Screening and scoping the assessment

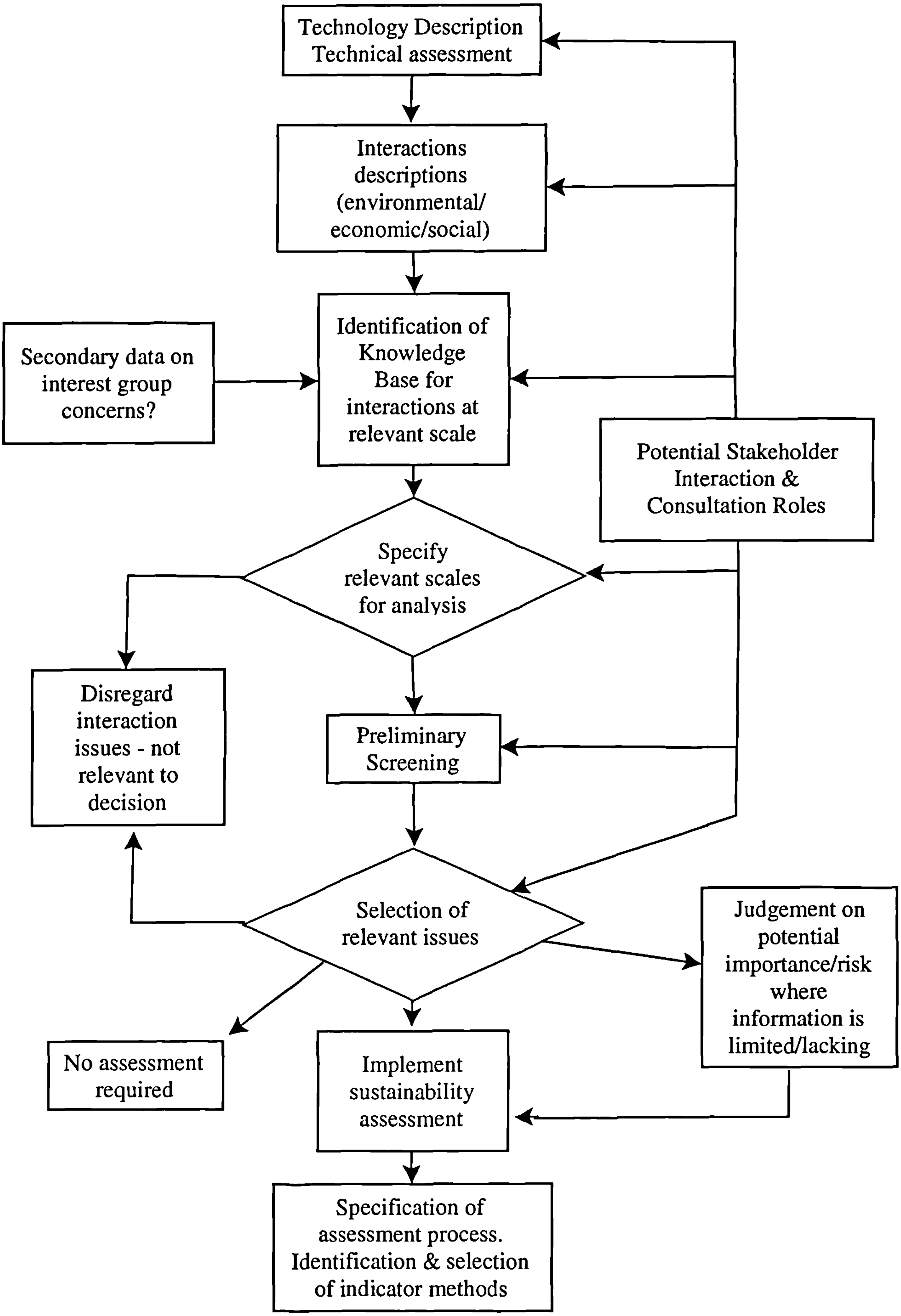
The first stage of sustainability assessment at any level would involve a screening and scoping exercise such as applied in a range of existing methods, such as EIA or CBA. Three parallel, interconnected areas of enquiry are required to establish the relevant indicators, criteria and methods for detailed assessments. These include:
- issues of importance for the specific analysis.
- stakeholders in the process.
- relevant scales of interaction.

The scoping process may be based on secondary data, or involve preliminary data collection from a range sources and interest groups, in the process of identification of relevant issues. The stages of scoping are as follows (see Figure 12.1):

Description of the technology, in terms of type of system, site characteristics, resource requirements and outputs (product and byproducts/ wastes).

Technical and financial viability: the investors perspective. Financial assessment procedures will be a fundamental component of any sustainability assessment. The starting point will therefore require assessment of viability on technical and financial criteria. Clearly if the first of these is not fulfilled, further assessment is not required. In some cases, failure to fulfil financial criteria may still warrant further analysis, as there may be economic justification for the activity, and as such economic measures to stimulate financially viable systems for investors may be justified.

Figure 12.1 Screening and Scoping for Sustainability



Description of the main interactions with wider systems of environment (including local and wider resource flows), social and economic spheres. At this stage the broad features of the technology will allow the first selection of relevant issues: for example, a systems based on natural sources of feed from the culture environment, thereby removing nutrients, will not require analysis of impacts of waste discharges associated with nutrient and organic enrichment. Identification and preliminary participation of different stakeholders may be required to identify areas of interaction. As part of this process, a standard 'sustainability features diagram' is proposed here as a means to highlight the needs of the assessment (and later as a framework for summarising features in presentation of results). This builds on a standard input-output model for technical and financial specifications, to include 'externalities', in terms of social, economic and environmental aspects, including the identification of links between inputs and the resource base from which they are derived. This does not set out to make value judgements on sustainability, but to describe system linkages[1].

Identification of the knowledge base for the main relevant features, in terms of data available, assessment methods available, risks and uncertainties. (This may involve participation/ consultations with a range of specialists, government and regulatory bodies, specialist interest groups, and local people, where relevant, and draw on generic systems information, such as pollution and resource use characteristics, and environmental capacity).

Specification of the relevant scale of analysis; at this stage certain relevant features may be dropped from the analysis depending on the scale at which the analysis is being conducted (eg the firm, local, or national): industrial energy analysis will be relevant in a national sector study, but may not be considered relevant at the level of the firm. Some aspects may be relevant at all levels, depending on the situation.

Preliminary Screening and selection of issues for further analysis; here a brief analysis on available information is required to identify requirements and issues for further analysis, and those which are not relevant. The outcome may be a decision that further analysis is not required.

[1] examples of 'sustainability features diagrams' for a range of systems are presented in the next Chapter, Figures 13.1 -13.4.

Judgement on potential importance of areas lacking information based on knowledge of impacts or behaviour of interactions from other activities: eg knowledge of behaviour of antibiotics and chemicals for the specific system may be limited, but general knowledge of potential impacts, or uncertainties, may suggest caution. The question of reversibility is also important. These issues should be carried into the sustainability assessment.

Definition of requirements for the detailed assessment; outline broad objectives and terms of reference for the assessment process, including broad description of potential assessment methods and indicators. Outline role of different stakeholders in the process (specialist consultants, government and non government bodies, special interest groups, relevant community groups).

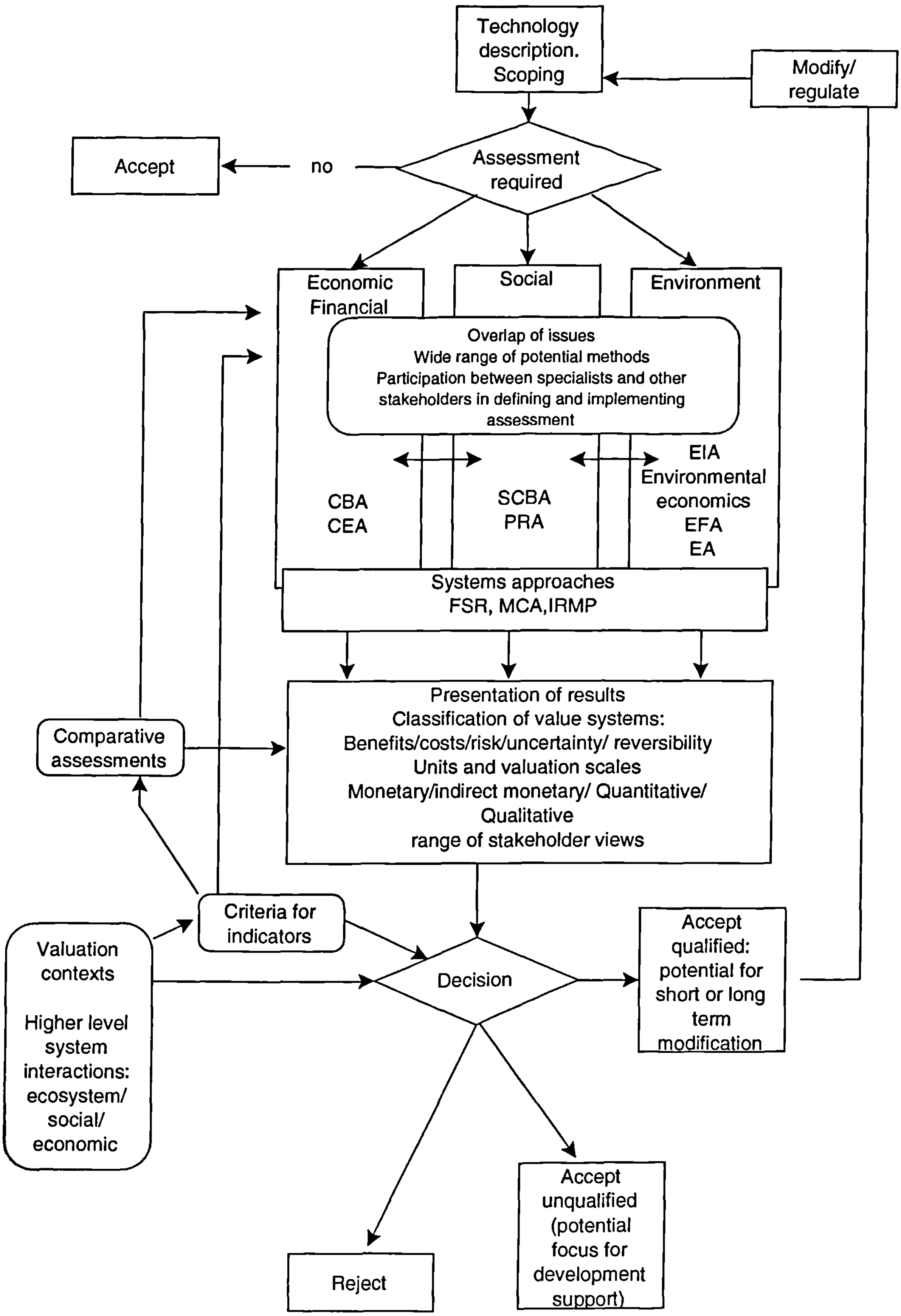
12.2.3 Implementation of the sustainability assessment

Having established in broad terms the needs of the assessment, implementation (Figure 12.2) can be see to comprise two principal stages:

Detailed assessment of issues of importance; here the selection of specific appraisal methods, indicators and criteria, relevant to the particular assessment, will be required, primarily involving specialists, and potential participation of a range of other stakeholders. A wide range of potential methods may be applied; it is important that these are clearly set in the context of other activities, systems capacities (eg waste assimilation capacity), the potential for conflicting or complementary interactions, and alternative opportunities. Where appropriate, aspects of the technology which might be altered to improve sustainability characteristics should be identified.

Presentation of the results of all detailed analyses, and the scoping process by which these elements were identified. This will include a range of information which has been reduced to "results" and "conclusions". These will consist of different and often incomparable (or irreducible) value scales, including quantitative monetary and non monetary assessments, and more qualitative judgements.

Figure 12.2 Sustainability assessment process



See page xiii,Table of Contents, for acronyms

The extent to which these judgements have involved participation of different stakeholders in the process must be clearly identified. Areas of disagreement and dispute should be acknowledged.

How this information is presented is less important than how it is used in the decision making process. However, it is important that the relevant factors and valuations are not hidden in large reports. Presentation should aim to be concise, and where possible visual methods for dealing with data, including qualitative value judgements, should be used. The latter might involve the use of relative or ordinal scales, measuring identity and rank. Examples of how information may be presented in the form of a (highly simplified) 'sustainability features analysis', to complement the linkage description of the 'sustainability features diagram', are presented in the following chapter.

12.3 Use of the information in the decision making process

Having reduced the wide range of potential investigations into a number of relevant valuation scales, set in terms of indicators and established criteria (if available), the decision making process must then weight these against alternative development options (of which one would be the no change option). It is at this stage that the wider context of development goals, and alternative options, is required for decision making on the desirability of a particular activity. This applies both at the national and local level, concerning decisions relevant to sectors or firms. There may be considerable potential for accruing information, and cross reference from one assessment to another, within, and between different sectors.

The output of this analysis may be a decision that the system or technology is acceptable, or unacceptable in terms of meeting sustainability objectives. In many cases, however, the result will not be clear-cut. In these, the assessment may provide pointers, to perhaps provide a qualified acceptance of a particular technology for future development or to help identify aspects of existing activities which might be changed. This may involve short and long term goals for technological development to move towards sustainability objectives: thus the criteria for acceptable activities, in a given context, from a sustainability perspective, are likely to change over time, reflecting the evolutionary nature of change required for sustainability.

Implementation of such change would therefore also require the identification of policy measures required to achieve these objectives. This could imply restrictions (or incentives) aimed at specific developments or sectors. The features of change might require policy changes at a macro-economic level (energy efficiency being a particular example). There may also be monitoring requirements for specific developments or technologies, and specification of research objectives in respect of specific areas of uncertainty and concern.

Chapter 13 Assessment in practice: illustrations for different technologies and scales

13.1 Introduction

One of the objectives of this study was to seek methods for sustainability assessment workable across the wide range of technologies and circumstances which comprise the aquaculture sector. It has been concluded that part of the assessment must include the selection of appropriate indicators and methods for specific contexts. Nonetheless, a standard approach to the process, as outlined above, may be applied. As part of this process, a standard format 'sustainability features diagram' has been proposed here as both a means to clarify the needs of the assessment, and as a framework for summarising key features and system linkages in presentation of results (Figure 13.1).

Based on the identification of sustainability features here, the results are then presented in a 'sustainability features analysis', which provides a summary of the outputs of a range of analyses, in terms of positive and negative features, individually ranked in terms of various levels of importance. This will involve a range of valuation mechanisms and value judgements. The benefits of applying a standardised format (not implying standardised selection of methods or valuation mechanisms) are:

- it provides a simple visual summary of all input-output characteristics which can be applied to any system, and considers interactions in terms of social, economic and environmental aspects (including potential for assessment in terms of local, or primary impacts, and the wider resource use, or secondary impacts)

- each input and output box represents a potential aspect for further investigation, and should raise questions, to help in the process of establishing appropriate boundaries for each aspect of the analysis, and potential assessment methods.

- each aspect can represent the focus of debate/ discussion as to significance from a sustainability perspective. This can represent the framework for pulling together the specialist aspects of the assessment, and the development of relative valuations.

Although this process can only really be effective in its real-life application, the following examples illustrate the potential outcome of application at a sectoral level, with comments on how this might vary at local and firm levels. These examples also serve to highlight issues which may be generally relevant to analysis of similar systems in different contexts.

13.2 Salmon farming in Scotland

13.2.1 Overview

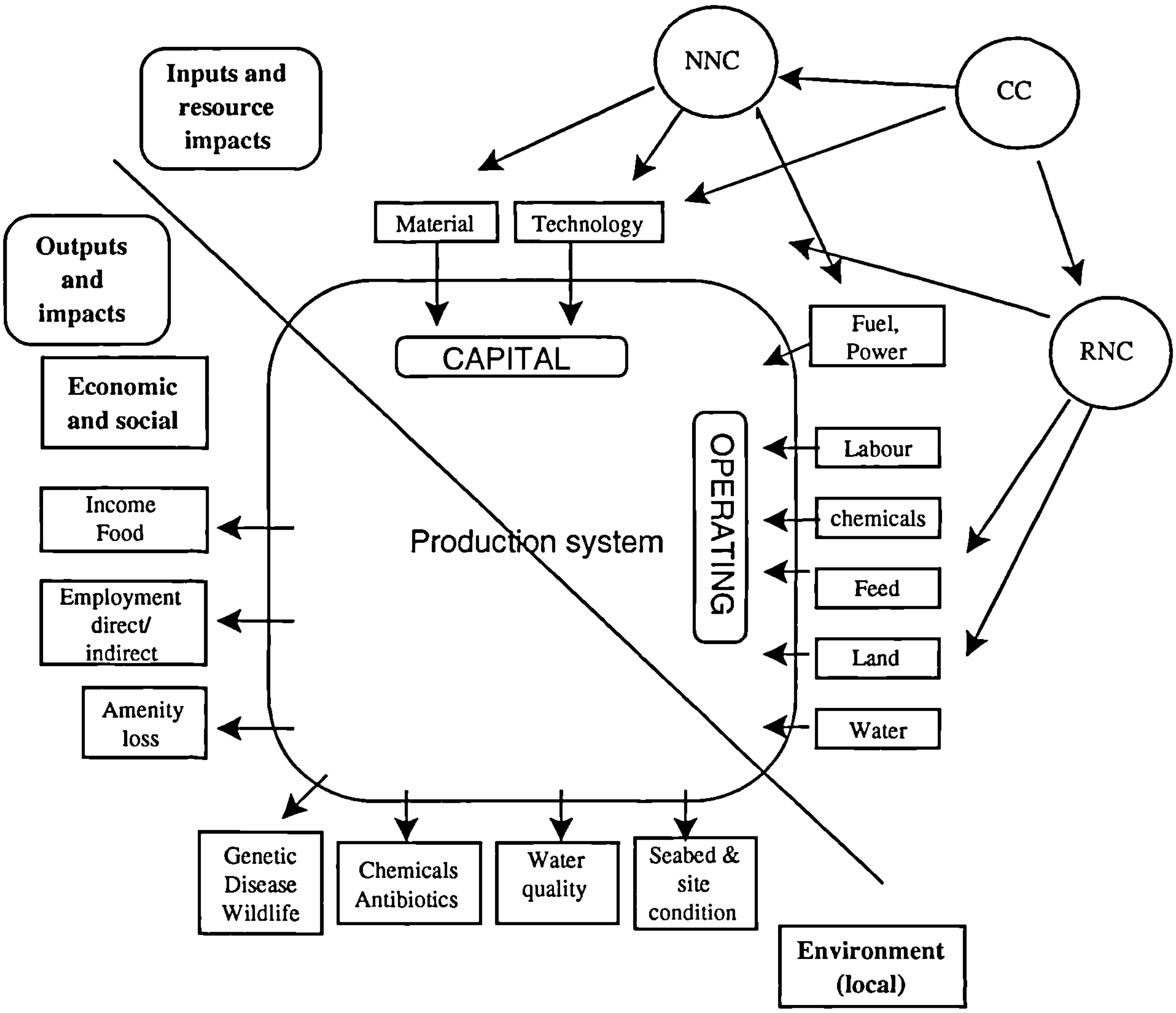
Sectoral overview, system description and interactions.

The salmon farming sector in Scotland is a relatively new industry, growing from less than 1000 tonnes 1980 to almost 50,000 tonnes in 1993 (SOAFD, 1994). The expansion was supported with loans and grants of about £40 million from local and European development funds (Warren, 1991). Advocates of this industry have highlighted the importance of the economic and social benefits of job creation in the areas of the Highlands and Island where alternative opportunities were limited. However, this rapid growth, and the lack of any clear policy for control, has lead to concerns from environmentalists about the negative impacts of this development, particularly in terms of water quality, amenity and wildlife. The characteristics of these impacts, modelling and monitoring methods, and approaches to their valuation, have been discussed in general terms earlier. There have been a number of sectoral studies on these issues (Warren, 1991; Maitland, 1987; NCC, 1989; Pepper, 1988; CRC, 1987). A description of marine salmon farming technology, and an example of a financial and energy analysis was presented in Chapter 6 (and Annex 4). A sustainability features diagram is presented in Figure 13.1.

Aspects of significance to the analysis

A sectoral level analysis will, by necessity, seek to draw general features from specific studies of systems and aspects of the sector. This is likely to be based largely on secondary data, where available. In this case a relatively good knowledge base exists. For the sectoral level, all issues detailed in Figure 13.1 are relevant to the initial investigation. For local level assessment, issues of energy use and biological energy

Figure 13.1 Sustainability features diagram- Intensive salmon farming.



NNC = Non renewable Natural Capital
RNC = Renewable Natural Capital
CC = Cultural Capital

efficiency may be dropped. While these are critical elements of sustainability, the mechanisms by which these characteristics might be influenced will not operate at a local level.

13.2.2 Sustainability analysis: potential conclusions for a sectoral study

An example of a potential outline classification of positive and negative features of this sector, in economic, social and environmental impacts, are summarised in Table 13.1. The presentation here (and for following examples) is simplistic in that it only considers features in terms of limited scales; positive features of high and low significance, and negative features of high, low and uncertain significance. In a full analysis a wider scaling range may be appropriate, and would need to be accompanied by detailed analyses, represent views and values of a range of stakeholders, presenting results in monetary, quantitative and qualitative terms, as discussed above. Broad sectoral generalisations based on secondary data will not necessarily reflect issues of importance in specific developments. The final assessment will represent a negotiated compromise between different interest groups and specialists. Local level assessments are more likely to require field studies, impact modelling and local participation. As this is an illustration, the views presented here are based on assessments of the available secondary information, and value judgments which have not directly involved relevant stakeholders: however, the literature sources could be seen as broadly representative of a range of views.

Economic aspects

Positive: economic benefits of the salmon industry can be assessed in terms of total jobs, direct and indirect, national tax revenues and savings in social security benefits. Standard economic methods can be applied in the analysis of these aspects. In this analysis the economic benefits are given a high significance, in terms of meeting short term economic needs in rural Scotland.

Negative: In general, there is no evidence of direct resource conflict in terms of lost or displaced economic activity associated with the aquatic environment or site area. An issue of potential concern is the impact on tourism (one of Scotland's most important sources of income), through amenity loss, in terms of visual and physical impacts on

Table 13.1 Sustainability features analysis: salmon farming in Scotland

Impact, methods and valuation	positive importance		negative importance		
	high	low	high	low	risk? (precaution)
Financial/ Economic CBA + (£)	•jobs, •exports			•tourism (envt)	
Social PA (QL).	•community			•amenity (envt)	
Environment local/region EIA+ PA (QT & QL).				•organic, (sediments) •nutrient (water) •wildlife	•chemicals •antibiotics •genetic •disease
Environment/ wider EA, EFA (QT)			•NNC •RNC		

Acronyms- CBA: cost benefit analysis. PA: participative appraisal. EIA: environmental impact assessment. EA: energy analysis; EFA: ecological footprint analysis. NNC non renewable natural capital. RNC: renewable natural capital;
Measures- £- monetary; QT-quantitative; QL - qualitative

"pristine" environments. However, there is little hard evidence by which any significant economic value can be placed on this. In this assessment, this factor is considered of low significance. This issue, however, is of importance beyond the sectoral analysis, in relation to the wider development policy in these areas. Investigation of these aspects by environmental economic methods might be a relevant area for research.

Social and community

Positive: in many communities fish farming helps maintain the population above a critical level, below which local services, such as schools and local shops, would not survive. Thus the benefits may be more important than the direct and indirect employment, in that loss of these services can cause further loss of rural population, representing issues of social as well as economic importance. An issue of local significance might be the question of local versus outside recruitment, although all employment in the locality will contribute to community viability.

Negative: loss of amenity, as for tourism, may be a relevant factor to the quality of life of local people. This is a controversial aspect. Disagreement is often manifest in conflict between 'locals' and 'incomers' (migrants, non local special interest groups, holiday home owners). At a sectoral level this aspect might be attributed a low significance: this is more a matter for local assessment, where participation of these different stakeholders becomes relevant.

Environment

Issues of environmental impact include both local impacts at the development location, and the wider impacts in terms of resource use. These are considered separately below.

local, regional

Positive: there appear to be no environmental benefits from this technology.

Negative: in this analysis, there are considered to be no highly significant negative impacts in terms of the regional coastal environment. Nutrient enrichment and organic loadings, at a sectoral level, considered in terms of broad geographic coastal regions, is attributed a low significance. At this level, it is important to consider total impact of the industry in comparison to other environment users and sources of pollution, and wider policy on water quality standards: only in this context can the relative significance of this industry be assessed. Meaningful analysis at this level may require consideration of activities within relevant hydrographic boundaries for coastal environments. The conclusion here, for the Scottish industry, differs to that reached by Folke et al. (1994) for the Swedish industry, discussed in Chapter 9.

A local sustainability assessment might judge these impacts to be more important at specific sites and regions: in enclosed areas, local enrichment and site related impacts may threaten the commercial sustainability of the operation itself, or features of special interest or value (eg special scientific interest, outstanding beauty and recreational value). Impacts on wildlife are the subject of conflicting views. There may be specific areas of local concern in terms of allowing development, but this is also an aspect where policy on standards and control measures may be required.

Elements of uncertainty and risk: These represent aspects where there is reason for concern and conflicting debate, but a lack of information to judge their potential importance. In sustainability assessment these must be included in the valuation and decision making process. In salmon farming these include chemical and antibiotic use, and the effect of disease and genetic impacts of fish farm stocks on wild fish populations. At a policy level there may be several ways of dealing with these: research may be commissioned to provide more information, while business goes on as usual. However, given limitations in ability to determine importance of low level effects in the long term, a precautionary approach would suggest that moves should be made to reduce these uncertainties without waiting for firm evidence to suggest negative effects. This process could be implemented through a number of means:

-legislation, immediate: eg restriction of use (chemicals, antibiotics). This brings potentially serious constraints to industry, and potential loss of social and economic benefits.

-legislation, gradual or delayed imposition of constraints: this may provide industry the opportunity to develop alternative production procedures. This could, for example, involve the use of tradeable permits for the use of specified substances, or charges on their use, based on the principle of polluter pays.

-information and cooperation: search for mutually beneficial change, through research and technological innovation, by which management practice develops to reduce the need for potentially harmful practice, and may also bring commercial advantage (however, if potential for the latter is not clear, this may only arise through threats of legislation, above).

These aspects require a strong policy framework, and clear and workable institutional structures. The principles of participation apply at this level, representing the process of communication between industry, concerned interest groups, scientific institutions, and policy makers. This is required to develop some workable consensus on achieving change, while maintaining benefits.

Environment/ wider impacts

Positive: there appear to be no wider environmental benefits from this technology.

Negative: In this case the resource use efficiency of this sector is attributed a high, negative significance, in view of the dependence on a wide resource base of NNC (fossil fuels) and RNC: this valuation, however, requires some qualification.

In the case of NNC, intensive systems such as this simply reflect the economic environment in which they operate, in which the economically efficient level of energy subsidy reflects the energy policy at a macro-economic level. Because salmon farming has been identified as a resource inefficient technology does not mean that this sector should be isolated and penalised for these features: the technology still represents an important provider of livelihoods to many rural communities. However, the long term sustainability of salmon farming will be significantly influenced by the availability and costs of non renewable resource inputs: in an environment of increasing energy costs, either by default (through reduction in supply in the long term) or by active policy decision, such intensive production processes must increase efficiency, and /or command higher prices for products, or they will cease to be viable.

The potential for macro economic measures to pursue increasing efficiency of resource use in food production will also be set in the context of priorities throughout the economy: food sectors may be considered more important than other high energy activities. Therefore while the pursuit of efficiency may remain a key objective in technology development, energy subsidies to intensive food production may still represent an acceptable resource allocation on the path towards more sustainable societies.

The requirement for RNC, most importantly in the form of industrial fisheries, is also considered to be a negative feature to reflect the relative ecological inefficiency of feeding fish protein to fish. However, this will not necessarily represent a resource threatening activity, if the fishery concerned is sustainably managed. Further, the choice in resource allocation, although in some views inefficient, may still be judged to be the most desirable use of those resources in specific circumstances.

As suggested earlier, these issues are not relevant to local level analysis, but may be highly relevant to the sectoral analysis. There remains the problem of how this information is used at the policy making level. Alone, these measures are only suggestive, but set in the context of a national sustainable development plan, and in comparison to other sectoral activities, there are several ways in which such information might be used:

- to assist in the development of national resource accounts, "footprint" assessments and energy audits, and contribute to the process of indicator development. These are likely to represent key components in the process of formulating national sustainability development objectives and policies.

- to assess economic impacts of changing energy policy (eg taxation) on sectoral activities

- to direct development support towards activities which increase resource use efficiency (eg applying comparative efficiency criteria for alternative development options).

13.2.3 Conclusions

This analysis suggests that while intensive salmon farming is an important activity in sustaining rural communities, and the environmental impacts in terms of pollution are relatively low, there are concerns which question its long term benefits as a food production system and economic activity, in particular in terms of resource use efficiency. However, whether this sector ceases to be viable, or acceptable in the long term is not the issue: rather it is the question of how this process can contribute to the national, larger and longer term sustainability perspective. While salmon farming has come under considerable scrutiny in recent years, the problems occurring at the sectoral level are characteristic of the approach to forestry, agriculture and livestock production in the UK: these are largely intensive monoculture systems which feature nutrient enrichment of local ecosystems, the use of chemicals with uncertain long term effects, and, in the case of livestock and agriculture, high energy demands. A significant component of livestock production (primarily poultry and pigs) involves heavy dependence on marine fisheries products for feeds. The visual and amenity impacts of modern agriculture and forestry may be significantly more important than the relatively small area of impact of salmon farms.

It is therefore clear that the policy issues involved in developing more sustainable natural resource based sectors, while meeting the needs of present economic and social welfare, are the subject for higher level decision making than those concerned with activities of any specific sector alone. This in turn requires a higher level framework of indicators and criteria, and goals into which sectoral plans can be developed.

Returning to the specific case of salmon farming in Scotland, criticism has been levelled at the lack of clear policy for planning at a local level, characterised by the lack of a single responsible authority, vested interests, and lack of participation and consultation. This has been attributed to the relatively rapid growth of an industry which bridges different areas of jurisdiction associated with the coastal environment (Warren, 1991). However, the growth has stabilised, community dependence well is recognised, and improved practices are being developed and implemented. Thus this industry, in economic and community terms, may be seen to have a role in the sustainability of the region, irrespective of whether, due to changes in resource availability, costs, or resource management policy, this continues to be the case in the future.

13.3 Mussel farming in Scotland

13.3.1 Overview

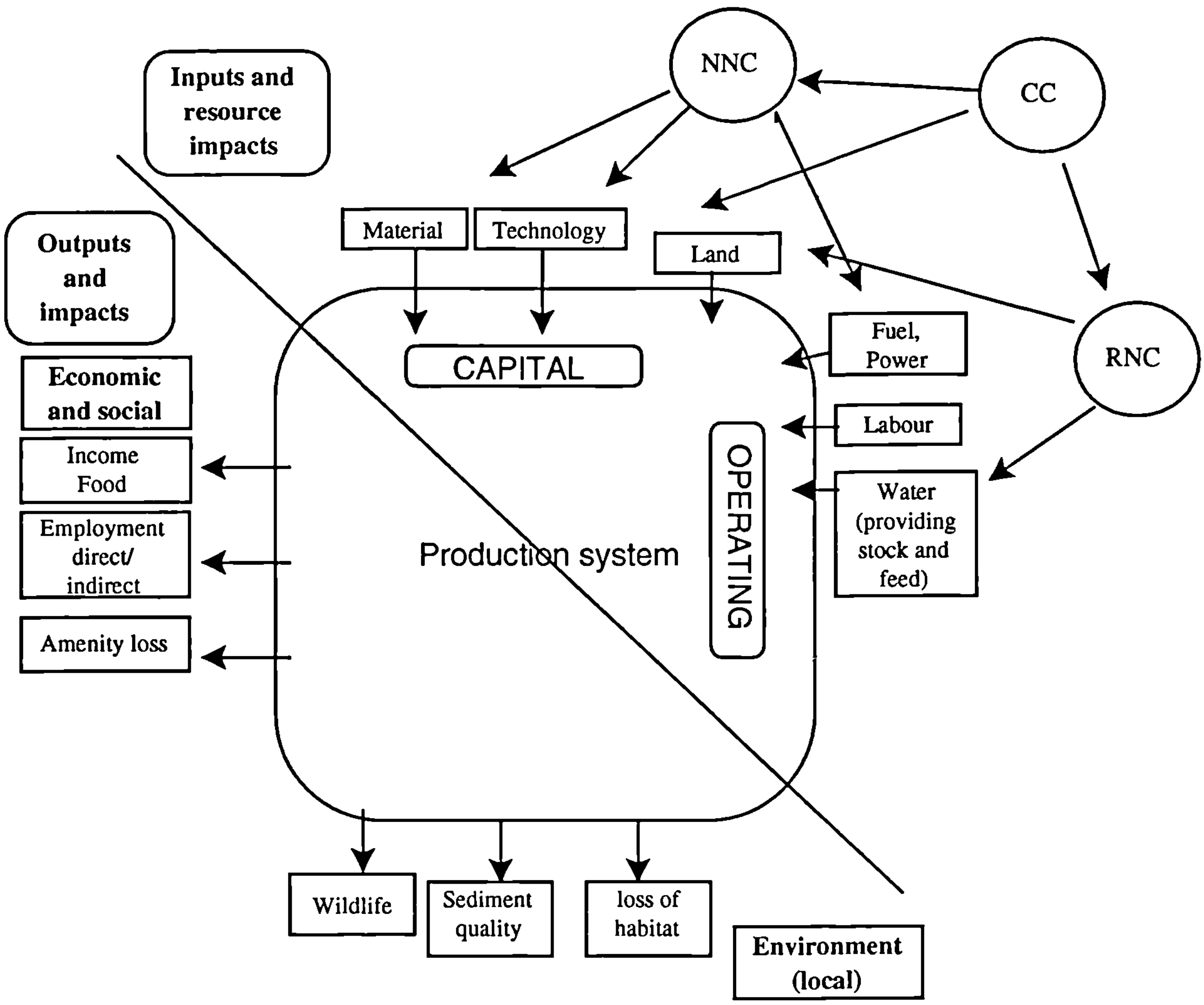
Mussel farming in Scotland has grown significantly over the same period as the salmon industry, but in scale and economic impact is considerably less important. It generally represents much smaller businesses, with owner operators, and relatively low levels of investment. In 1993, the total production was about 700 tonnes, having fallen from about 1000 tonnes in 1991, as a number of companies ceased trading. In 1993, of 40 active companies, 4 were responsible for about half of the total output, while 24 produced less than 10 tonnes. Of about 350 direct jobs in this sector, almost 80% were part time (SOAFD, 1994b). One of the principal constraints to the growth and success of this sector is that, as a labour intensive system, returns to labour are low. A study of the potential costs and returns from systems with an annual production of 16 and 32 tonnes estimated returns to labour of between £30 and £50 per day (HIDB, 1989). These figures were net of a capital grant of 70%. The commercial sustainability is highly sensitive to losses, which can be caused by loss of stock through storm damage and predation, and also recent problems of product quality (E-coli associated with human and livestock wastes entering aquatic systems) and costs of depuration. In 1993, 30 registered companies were not trading (SOAFD, 1994b).

Interactions of mussel farms with other systems are illustrated in Figure 13.2. The basic characteristics of shellfish farming interactions with the environment have been discussed in Chapter 4, and a financial and energy analysis presented in Chapter 6 and Annex 7.

13.3.2 Sustainability assessment: potential conclusions of a sectoral study.

A summary of a potential analysis, on the same basis as applied above, is presented in Table 13.2. Economic and social aspects of mussel farming can be considered to be positive, and of high importance, although considerably less significant than for salmon farming, given the relatively small scale of the industry. Concerns about impact on amenity value of the local environment, in terms of the visual impact of the structures, are similar to those for salmon farming.

Figure 13.2 Sustainability features diagram: Longline mussel farming.



NNC = Non renewable Natural Capital
RNC = Renewable Natural Capital
CC = Cultural Capital

Table 13.2 Sustainability features analysis: mussel farming in Scotland

Impact, methods and valuation	positive importance		negative importance		
	high	low	high	low	risk ? (precaution)
Economic CBA + (£)	•jobs			•tourism (environment)	
Social PA (QL)	•community			•amenity (environment)	
Environment local EIA+ PA (QT & QL)	•nutrients (water)			•organic, (sediments) •wildlife	
Environment/ wider EA. EFA (QT)	•RNC •NNC				

Acronyms- CBA: cost benefit analysis. PA: participative appraisal. EIA: environmental impact assessment. EA: energy analysis; EFA: ecological footprint analysis. NNC non renewable natural capital. RNC: renewable natural capital;
Measures- £- monetary; QT-quantitative; QL - qualitative

These systems differ significantly in their environmental interactions. While structures and sediment impacts are of a generally similar nature, and there may be some concern over wildlife, these culture systems remove nutrients from the marine environment. Given that most coastal waters are to some extent enriched due to human activities, this could be considered environmentally beneficial, thus a highly positive characteristic in sustainability terms. There are no controversial elements of environmental risk associated with this production technology. There are, however, regular, if relatively minor, human health problems associated with shellfish consumption.

The wider impacts of these production systems in terms of resource use is small in comparison to other animal production systems: the low trophic level of mussels, deriving growth from local aquatic productivity, indicates potentially low requirements for non renewable resources (demonstrated in chapter 6) and high efficiency in renewable resource use. Thus in efficiency terms this can be rated a high positive score for both RNC and NNC.

At a sectoral level, this analysis suggest that in terms of environment and resource use sustainability, policies which encourage development of this industry may be desirable. However, as noted above, the present industry has depended on significant development support, without which the commercial viability of smaller operations is questionable. The relatively small market in the UK, and significant competition on European markets, limit the potential development of this industry.

Therefore while potentially a desirable activity in the environmental system sustainability perspective, the marginal commercial viability (associated with a limited market capacity) limits the contribution to sustainability objectives in economic and social system, at least in the near future. In the event of significant expansion, the potential for increased environmental impacts should be noted; in some European countries, shellfish farming has developed to such an extent that sedimentation, restriction of water flow, and nutrient depletion has significantly influenced the production of the shellfish themselves. At the present scale of development, such effects have not occurred in Scotland.

Two important features of sustainability assessment are raised by this and the previous case: the potential for the conclusions of sustainability assessment to change with time, and the concepts of capacity, in terms of environment, social and economic systems. In the case of salmon farming, it was recognised that the present importance and viability may change with changes in the macro-economic environment and resource use policy or availability. Similarly, mussel farming, with limited economic potential at present, but high resource efficiency, might become more important in the future.

The concept of capacity, considered in term of economic, social and environmental sub-systems, is important for all assessments. Thus in theory, up to a certain level of activity, a particular type of production process might contribute to sustainable development, with acceptable trade-offs between these sub-systems. Beyond this, additional units may be considered unsustainable in terms of one or more of these subsystems, representing an unacceptable trade-off. In practice, incorporating concepts of capacity into the assessment is complicated by the fact that this may display progressive or threshold reductions in the perceived sustainability in any subsystem, and that definition of acceptable capacity will not be clear cut.

13.4 Shrimp farming

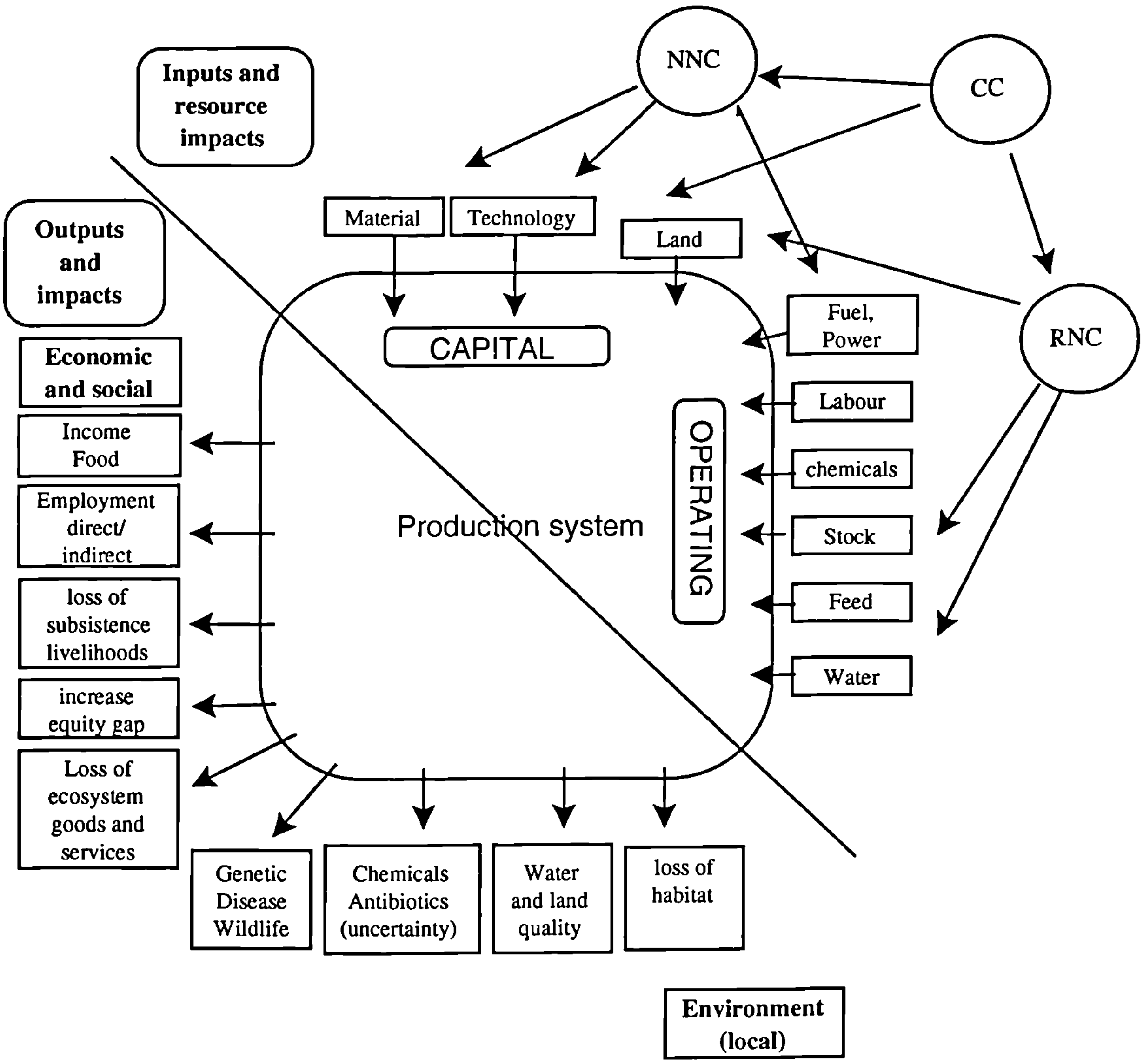
13.4.1 Overview

The shrimp farming industry is one of the most controversial aquaculture sectors in the context of sustainability. Extensive culture systems have a long history in Asia, but most of the rapid growth in this sector occurred during the last two decades. Production increased from about 0.2 million tonnes in 1975, to a peak of about 0.8 million tonnes in 1991. There has since been a significant decrease in world production, to 0.72 and 0.6 million tonnes in 1992 and 1993 respectively (Rosenbery, 1993), associated with a dramatic fall in production in China (70% reduced in 1993), and to a lesser extent in Indonesia and Ecuador. In earlier years, Taiwan also experienced a major collapse. These reductions were associated with a range of factors, including deterioration of the production environment and disease.

The rapid growth has occurred as a result of the high market value, and the significant returns these systems can generate, both to the investor, and to the wider economy in terms of export revenues. However, the pursuit of profits without due regard to the wider interactions with the development environment has not only caused failure of many commercial operations (for similar reasons to those observed in the trout farming operation examined earlier), but has also brought hidden costs in terms of wider impacts on other activities.

The major interactions between shrimp farming operations and other systems is illustrated in Figure 13.3. There is a considerable amount of secondary information available on the potential interactions on which a sectoral level analysis can be based. As in the case of salmon farming, a scoping exercise at a sectoral level would suggest that all issues and interactions will be relevant to the assessment, though at a local level, issues of energy efficiency would not apply.

Figure 13.3 Sustainability features diagram: Semi-intensive shrimp farming.



NNC = Non renewable Natural Capital
RNC = Renewable Natural Capital
CC = Cultural Capital

13.4.2 Sustainability analysis: potential conclusions for a sectoral study

A summary of the main features arising from this level of analysis is illustrated in Table 13.3.

Social and economic aspects

The benefits from this industry, in social and economic terms, are similar to those of the salmon farming industry discussed above. However, on the negative side, there is greater evidence of social and economic costs associated with changing resource use. This is due in part to the nature of the environment in which much of this development has occurred, and the type of production system, which requires large areas of land which may have other potentially important support functions. The social impacts are potentially more significant in developing countries where these environments support subsistence activities of rural people, who often lose out in the development process, thus increasing inequity.

Environmental aspects

The analysis of this sector is similar in many respects to that for salmon farming, in terms of the significance attributed to the wider resource use characteristics of these systems, the impacts of nutrient and organic outputs, and the use of chemicals and antibiotics. Most of the points made in the context of salmon farming apply here. Although the evidence suggests that water pollution has been a major factor in the failures recorded in this sector, this has been allocated a relatively low importance in the context of a sectoral sustainability analysis: such impacts can only be assessed in the evaluation of systems at a local level, in the context of the environmental capacity, and other pressures on that environment.

While many shrimp farming developments have not been sustainable in specific contexts, this production technology can not be clearly identified as unsustainable. However, for this sector to contribute to more sustainable development, a much wider range of factors needs to be taken into account in the development process.

Table 13.3 Sustainability features analysis: intensive, semi-intensive shrimp farming

Impact, methods and valuation	positive importance		negative importance		
	high	low	high	low	risk?precaution
Economic CBA +(£)	•jobs •exports		•displaced rural activities •fisheries		
Social PA (QL).	•community		•community •equity		
Environment local/region EIA+ PA (QT & QL)			•land use •salination •mangrove loss •wildlife	•nutrients (water)	•chemicals •antibiotics •genetic •disease
Environment/ wider EA, EFA (QT)			•NNC •RNC		

Acronyms- CBA: cost benefit analysis. PA: participative appraisal. EIA: environmental impact assessment. EA: energy analysis; EFA: ecological footprint analysis. NNC non renewable natural capital. RNC: renewable natural capital;
Measures- £- monetary; QT-quantitative; QL - qualitative

Unlike mussel farming in Scotland, which displayed favourable characteristics in environmental and resource use terms, but was limited in terms of the commercial potential, the unsustainable features the shrimp sector have, in many cases, been exacerbated by the very high financial returns (reflecting market capacity), which may have acted as an incentive to ignore limitations of environmental and social capacity. Thus the 'boom-bust' pattern of development in both Asia and Ecuador may have fulfilled the objectives of the early investors, who gained high returns over a short period of time. However, the longer term economic development of the resources involved may well have been compromised. This suggests that enterprises which offer very high returns (significant economic capacity), may attract levels of investment which takes production beyond the capacity of other sub-system sustainability objectives, resulting in potential for unsustainability at the level of the firm, or in the wider context. In these circumstances, development policy is all the more important to maintain growth within all subsystem capacities.

13.5 Small scale rural aquaculture

13.5.1 Assessment of the production activity

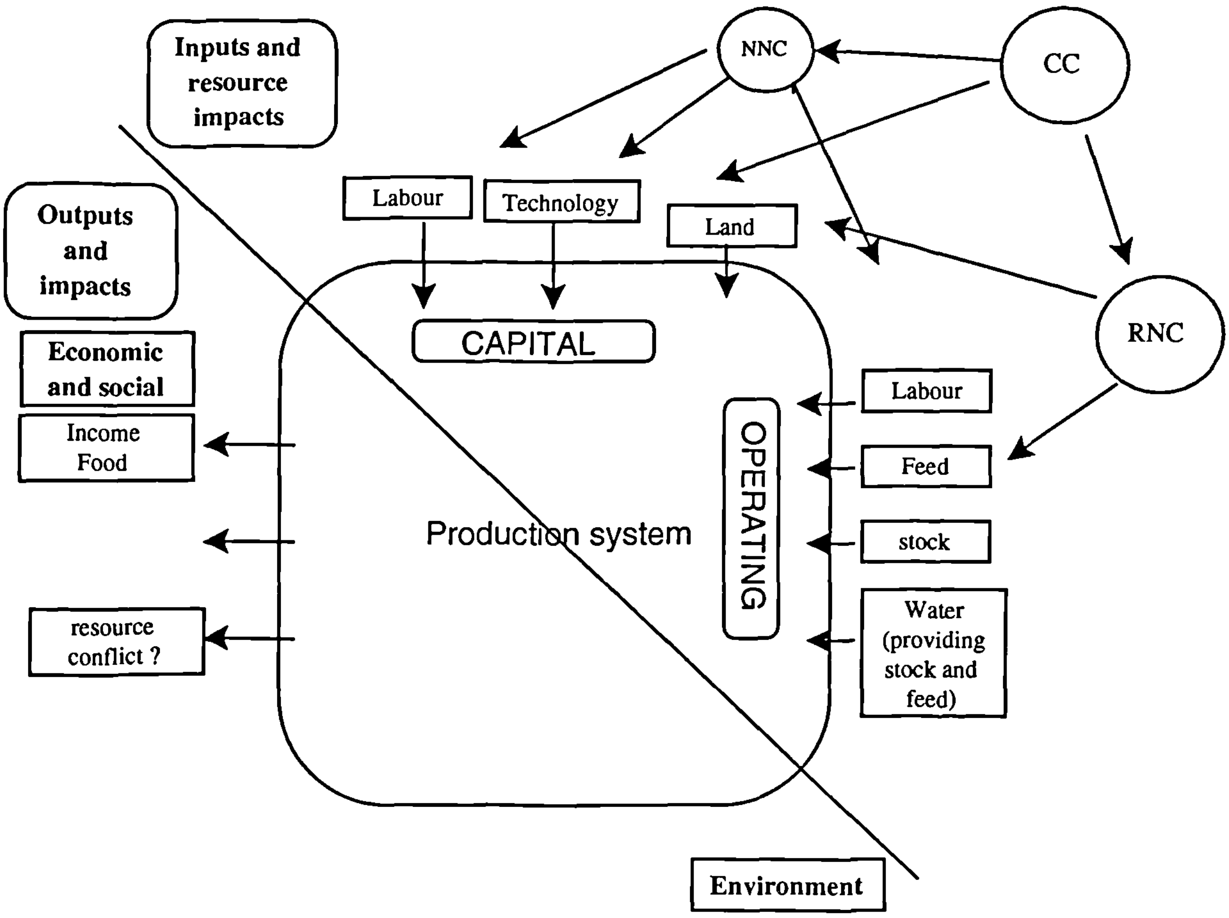
The assessment here is based on semi-intensive rural aquaculture development as described in Chapter 7. A summary of the principal features of this technology on a sectoral basis is presented in Figure 13.4. The scoping exercise applied at this level might suggest that a full sustainability assessment, with detailed studies of economic, social and resource use aspects would not be required. The outcome of such an exercise, presented in Table 13.4, might be as follows:

On the basis of economic, social and environmental criteria (local and wider scale), scoping suggests that these systems offer the potential to fulfil sustainability criteria (assuming that the farming operation is technically feasible, and there are the required on farm resources and technical skills for an economically viable system). Financially, and economically, these systems have the potential to bring significantly greater returns than alternative crops, assuming the scale of the development complements available resources. By increasing the diversity of production, they potentially increase the resilience of rural farming systems.

In social terms this could be seen to contribute, in a small way, to household security and local economic stability. At a sectoral level, there are no specific negative impacts. At local and household levels, there is potential for negative distributional effects in terms of access to and control of resources; although the evidence for this is limited, it may require to be assessed.

Due to the low level of intensity of these systems, there are unlikely to be any adverse environmental impacts. In resource use terms, these are highly efficient systems, requiring virtually no industrial energy (except where using agricultural products/ by-products requiring industrial energy subsidy). Ecologically, these systems offer the potential for high efficiency, producing fish low in the food chain, using resources available through integration with on farm activities. Productivity, is, however, low.

Figure 13.4 Sustainability features diagram: Semi-intensive tilapia (in smallholder farming systems)



NNC = Non renewable Natural Capital
RNC = Renewable Natural Capital
CC = Cultural Capital

Table 13.4 Sustainability features analysis: smallholder tilapia farming

Impact, methods and valuation	positive importance		negative importance		
	high	low	high	low	risk ? (precaution)
Economic CBA + (£)	•farm income •diversification/ resilience of farming system				
Social PRA (QL)	•household •community			•household? •community?	
Environment local EIA+ PRA (QT & QL)					
Environment/ wider EA. EFA (QT)	•RNC •NNC				

Acronyms- CBA: cost benefit analysis. PA: participative appraisal. EIA: environmental impact assessment. EA: energy analysis; EFA: ecological footprint analysis. NNC non renewable natural capital. RNC: renewable natural capital;
Measures- £- monetary; QT-quantitative; QL - qualitative

13.5.2 Assessment at the development project level

The main theme of the case study in Chapter 7 was the question of the development support required to establish a sustainable rural fish farming sector. The assessment was not concerned with the sustainability of the project itself, but with the capacity of such development efforts to create the basis for sustainable fish farming. Having made the broad assessment in favour of the potential technology does not mean that there is the basis for achieving sustainable development. As suggested earlier, this requires an assessment of the suitability in specific circumstances in technical, economic and social terms. It also requires an assessment of the institutional capacity, and approach to that development. The need for appropriate indicators, and development of this capacity, introduces requirements at higher levels than the individual project, or sectoral activity.

13.6 Costs and practicalities of implementing of sustainability assessment into the decision making process

As reviewed earlier, an important aspect in assessment of sustainability is the cost and practicality of implementation, balanced against the quality and usefulness of the information obtained. The process described above, as applied to several different aquaculture systems, is in principle, relatively simple. In practice, rather more detail may be required to back up the final sustainability assessment. The practicality and the cost of achieving this will depend on the detail of the investigations required. What is apparent from the preliminary analysis above is that much of the assessment can be based on information already available, from a range of sectoral studies and research programmes.

There are still areas of uncertainty, where further primary research and data collection is required, but the existing framework should provide the basis for a reasonable, if broad, assessment. It does not provide absolute answers, nor does it set out to do so. But it does fulfil the objective of presenting a range of different views of the system, and attributing relative priorities to these. As time goes on, the availability of relevant information, both from within the sector, and from studies of other systems, will increase.

At the level of the firm, where new developments or expansions of activity are required, there may be a need for specific detailed studies. These, however, will also be based on a range of existing modelling approaches and available information which will allow broad assessment of the impacts to be made relatively easily.

It can therefore be concluded that in comparison with the value of these industries at the sectoral level, and with the other costs of developing a business proposal, these costs need not be prohibitively high. Indeed, it might be argued that in many cases rationalising the existing requirements of planning and monitoring would achieve the desired objective of sustainability assessment without incurring any significant additional costs.

In many LDCs, however, there may be less country specific secondary data available, and a lack of skills required for sustainability assessment. However, the basic principles of understanding of impacts of different types of aquaculture technologies, on which there is a growing literature, are likely to be generally applicable. For example, in the case of shrimp farming , while there may be a lack of research in specific countries, there is a significant amount of information available to contribute to formulating a broad sectoral assessment.

In all cases, the value of a sectoral analysis is in the definition of broad characteristics and potential problem areas. In using this information for the planning of future expansion in this sector, it will provide a more comprehensive framework for the development of planning guidelines and development policy. Considerations of capacity, at appropriate levels in environment, economic and social systems, will represent an important feature of the assessment at all levels.

It is suggested that the cost of applying the concepts of sustainability assessment to the planning and policy making process need not be significantly greater than that of existing practice. Where costs may be incurred is in the development, or adaptation of institutional frameworks: this might involve staff training, improving communication between different levels of bureaucracy, and rationalising areas of jurisdiction (a point noted by Warren, 1991, in the case of the Scottish industry).

Chapter 14 Summary and Conclusion

14.1 Overview of issues and objectives

The importance of aquaculture as a means of food production and a source of economic activity and provider of livelihoods has been highlighted at the outset. In principle, this can be seen as an important and desirable form of development for meeting basic human needs. Indeed, some specialists recognise "an intense pressure to increase production to compensate for declining capture (fishery) supplies" (Csavas, 1994): thus forecasts for future growth into the next century suggests that this sector will become increasingly important on a global scale.

There is, however, evidence that some of the rapid and uncontrolled growth in commercial aquaculture production in recent years has been at the expense of the wider societal benefits, both current and future. In considering the potential for aquaculture to contribute to the welfare of future human society, there is a recognised need to examine these technologies within a wider context, embodied in the concept of sustainability, than that defined by immediate financial and economic benefits.

It was recognised that methods for technology assessment represented only one element of the "sustainability problem". A second relates to the problems of defining an appropriate context for the assessment, given the complexity, hierarchy and indivisibility in dealing with real world systems. The third concerns cultural and societal aspects, and problems of implementation of change, in terms of the institutional structures for resource management, and the cultural value systems which back up those structures.

At one level, the scale of the discrepancy between the needs for change as identified in the sustainability literature, and the current interactions between human and environment systems, might bc cause for considerable pessimism. To some extent there is also a perception of loss of confidence in the ability of rational and reductionist science to provide the understanding and approaches required to deal with the complexity and uncertainty embodied in these problems. However, while the perceived gap between the current situation, and some more desirable and sustainable global human society may be great, there is also a need for pragmatism. If any positive change is to occur, there must be workable strategies, however limited and uncertain, by which this process might start. Furthermore, while current approaches and understanding may be limited, it can be argued that they still provide the best available means to tackle the problem as currently perceived. Science is largely an incremental process, in which there will always be new boundaries and areas of uncertainty: recognition of this feature can be seen as an essential element of seeking approaches to managing for more sustainable development. Societal change (with the exception of revolution and war, which are likely to counteract progress towards sustainability) is also largely incremental. Thus it is unlikely that there will be any dramatic or positive revolutionary developments which change the way human society interacts with the environment: at best there is the hope that a process of evolution of understanding, and views of the world, will lead to the development of a more active pursuit of activities and resource management regimes which can satisfy the basic concepts of sustainability.

A small step in this process is represented in the objectives of this thesis, which set out to investigate the potential for the application of existing methods to the process of assessing sustainability of aquaculture.

14.2 Overview of the assessment process.

The output of this study is therefore the proposal of an approach which provides a relatively simple, practical, and cost effective means of organising available knowledge, methods and skills for a more holistic assessment of aquaculture development. The approach does not seek to make a definitive statement about the sustainability of a particular system or technology. This was recognised as beyond the scope of any assessment process. In developing this approach, the above analysis has:

- defined a generally applicable range of issues for consideration in the assessment process.

- provided a basis for the description of interactions of aquaculture systems within their development context in the form of a 'sustainability features diagram'.

- defined broad categories of indicators which may be applied to measure direction of change associated with aquaculture developments, in terms of sustainability objectives in economic, environmental and social systems.

- provided an analysis of a range of methods which may be selected for the assessment process.

- provided a broad framework for the selection of appropriate methods and valuation systems for analysis in a specific context.

- proposed an outline framework for presentation of sustainability features, in terms of positive, negative and uncertain aspects in the three sustainability sub-systems. In practice it was recognised that this will involve a wide range of views and valuations system, with the aim of explicitly revealing the value judgements and trade-offs involved.

These features provide a basis for seeking technological change, identifying research needs, and directing policy decisions, in terms of allocation of development assistance and imposition of legislative measures, to encourage the pursuit of more sustainable developments. It was recognised that this process must be viewed as a basis for the assessment of specific activities or sectors in the context of development options and objectives, at a range of scales.

The broad features of the approach may be generally applicable across the spectrum of aquaculture systems, but it is not necessarily proposed as a blueprint, rather as an example of how such an approach might be developed in practice. Any assessment process will be influenced by the value judgements of those involved, and constrained by the specific circumstance in which it is carried out. What is important therefore is not the specific details of how the end result is achieved, but how well these results reflect the wide range of issues involved in sustainability, and the potentially conflicting views of different stakeholders in the process.

Equally important, but beyond the main focus of this study, is the question of how such assessments are used. In this respect, development towards more sustainable practices will depend on the extent to which the political and institutional systems of decision making reflect the broad goals of sustainability. This will be influenced by:

- organisational structures, and the extent to which sectoral and institutional systems of decision making recognise ecosystem boundaries.

- the conflict between longer term sustainability objectives, and constraints imposed by the perceived short term needs of society, communities, or the institutions and individuals involved in the process.

In considering how positive change might come about, Slesser (1994) has argued that efforts to develop indicators of sustainability are themselves a relevant contribution. Thus any attempts to implement a systematic, multidisciplinary process of sustainability assessment, as with the analysis presented here, may offer a valid contribution to the process of change.

Given forecasts of significant growth in aquaculture production into the next millennium, this study suggests that existing knowledge of these systems and their interactions, however limited, is sufficient to enable the identification of the nature and direction of change required to initiate the move to more sustainable activities. Thus it appears that it is more a question of the societal will (political, individual) and capacity, rather than lack of knowledge, which will influence the course of development, in this relatively small sector, and society in general.

14.3 Further research and prospects for practical application of the model

The assessment process for any development proposal requires a pragmatic approach, which generates an output on which decisions can be made, based on the specified objectives and the best information available at the time. The model proposed here offers a framework by which the conventional boundaries of assessment may be extended to provide a more holistic analysis of trade-offs involved in any new development. While this may usefully highlight the principal issues and offer an analytical framework for sustainability assessment, it is only through practical application that the model can be refined to produce workable appraisal approaches. Clearly these may vary depending on the nature and location of the development. Thus at this level it is application to, and feedback from, real development decisions which is required, rather than further research.

Where there is a need for research is in the development of aquaculture technologies which better meet the goals of sustainability, as based on the broadly defined indicators presented in this study. This will be an ongoing process, in which incremental learning might be expected to assist in the evolution of new management practices and production technologies. To some extent this is already happening, with significant research efforts being focused on the development of less environmentally damaging practices, whether through new technology and/ or through improving management practice and system control; the potential role of integration of aquaculture with other complementary activities is also the focus of increased attention. Thus one might be optimistic about the potential for more environmentally and socially sensitive expansion of aquaculture industries in the future; in this sense the structure of the model described here can help to identify the appropriate contexts and relevant priorities, in both research and development, at sectoral and local levels. The approach will also be applicable in wider contexts, to examine systems in which aquaculture may be only an element.

As noted above however, the pace of change, and the extent to which the principles of sustainability influence decision making rests largely in the realm of the higher level political systems. In many cases, while there has been a growing political awareness, there has been very little real change in the policies of governments and activities of individuals. Commenting on the UK government White Paper (1990), "This Common Inheritance", Pearce (1994) observes that although "government understands many of the principles of sustainable development.... this readiness to speak the language ... has, as yet, not been translated into a comprehensive set of real and meaningful political outcomes".

The debate goes on. Will the action follow?

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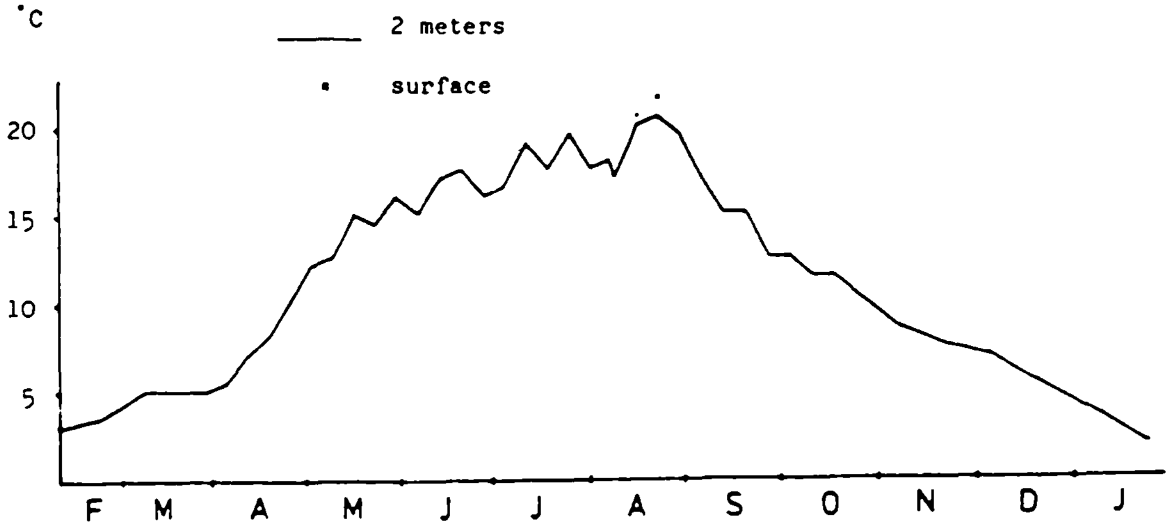
ANNEXES

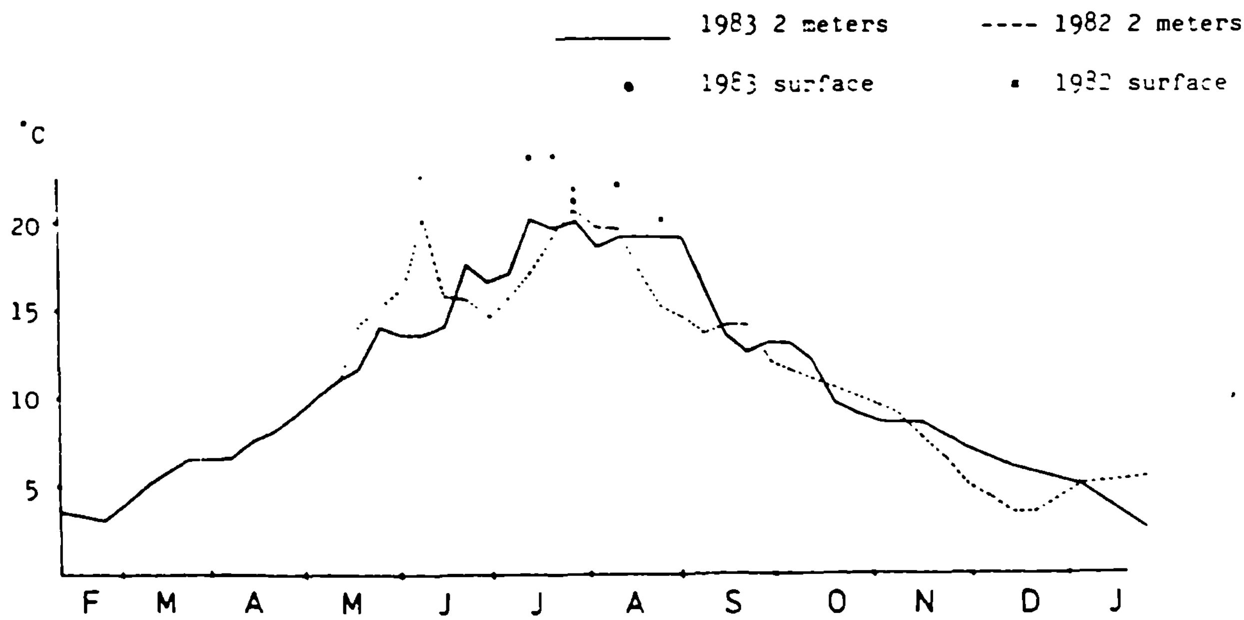
Annex 1 **Season changes in water quality in Loch Fad**

Annex 1. Figure 1 **Temperature**

1a. 1984.

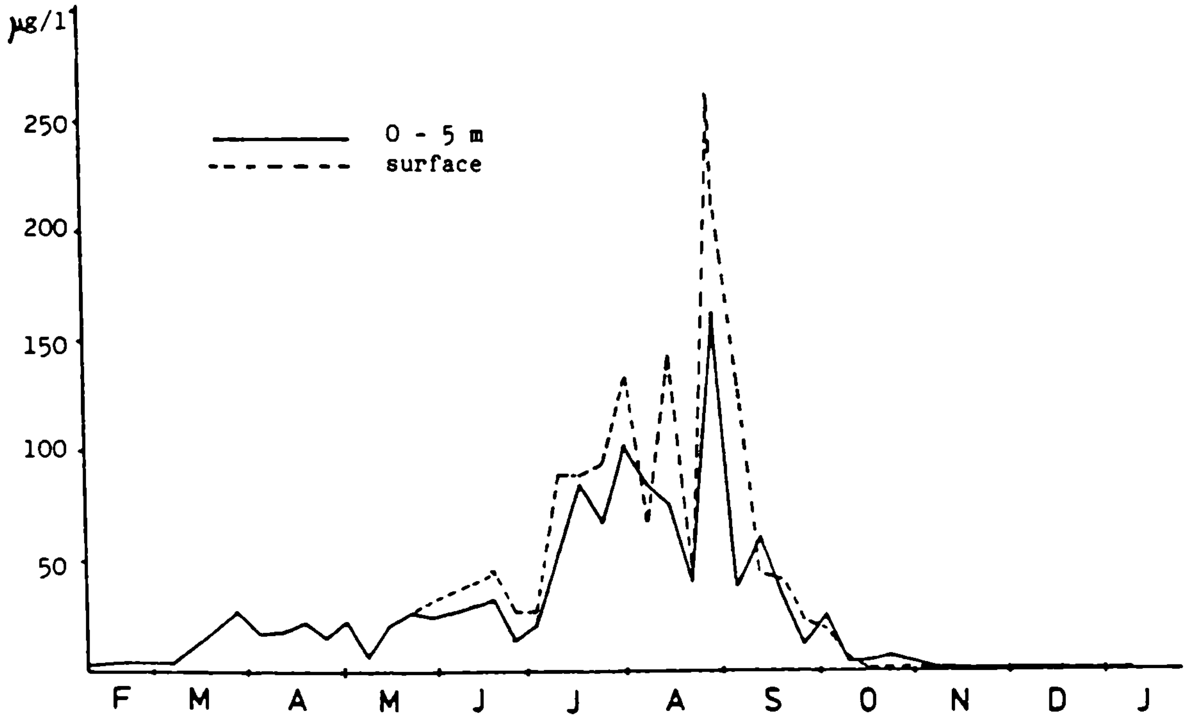


1b. 1983 & 1982.

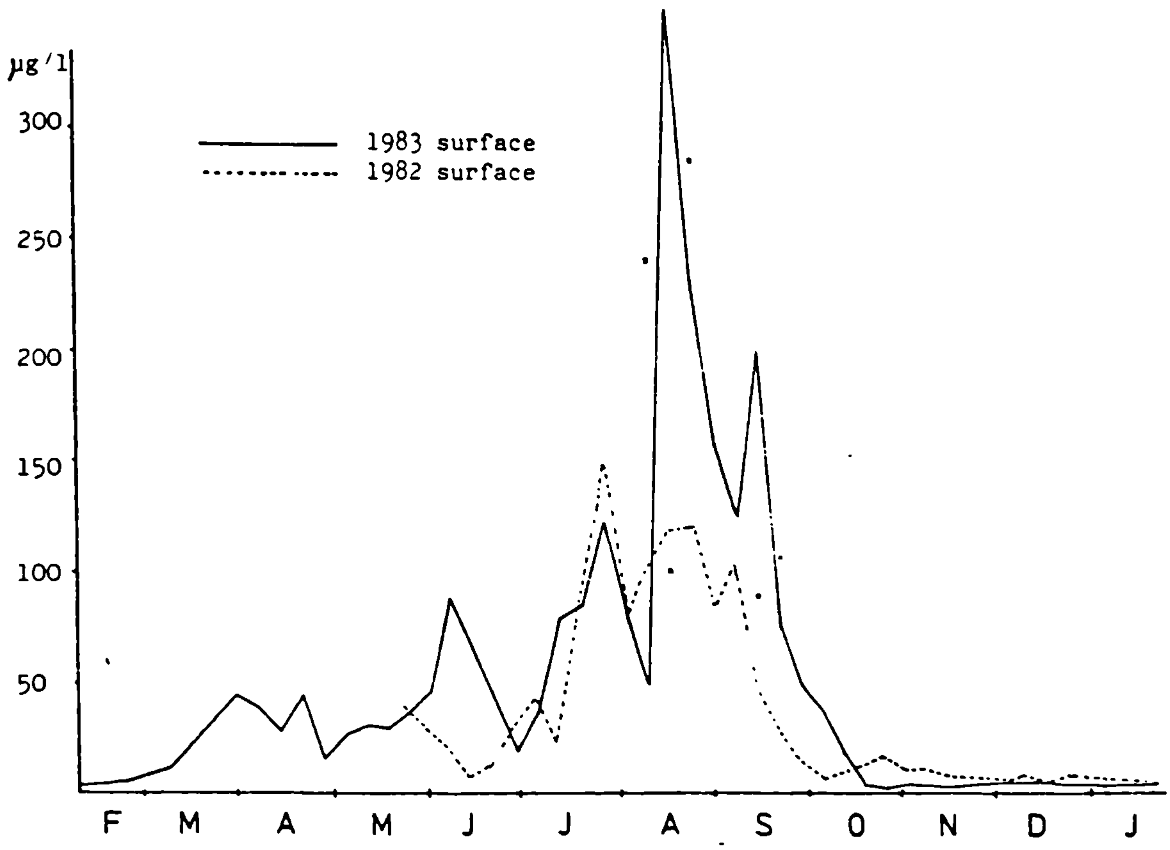


Annex 1. Figure 2 **Chlorophyll 'a'**

2a. 1984.

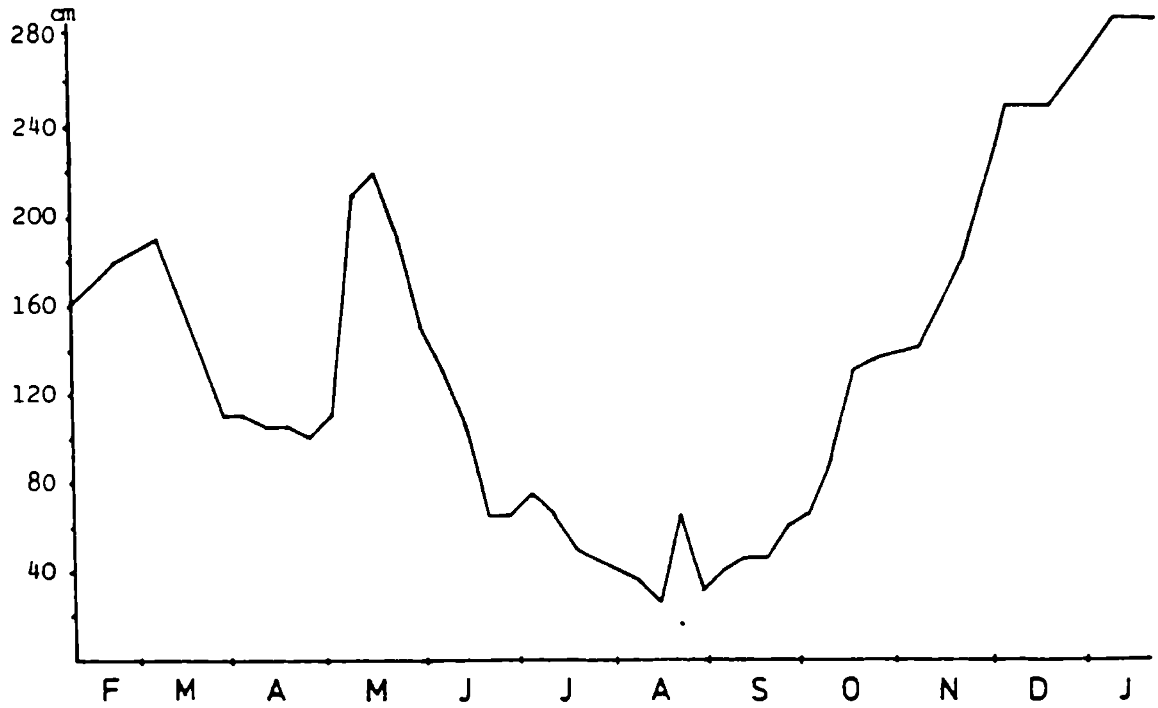


2b. 1983 & 1982.

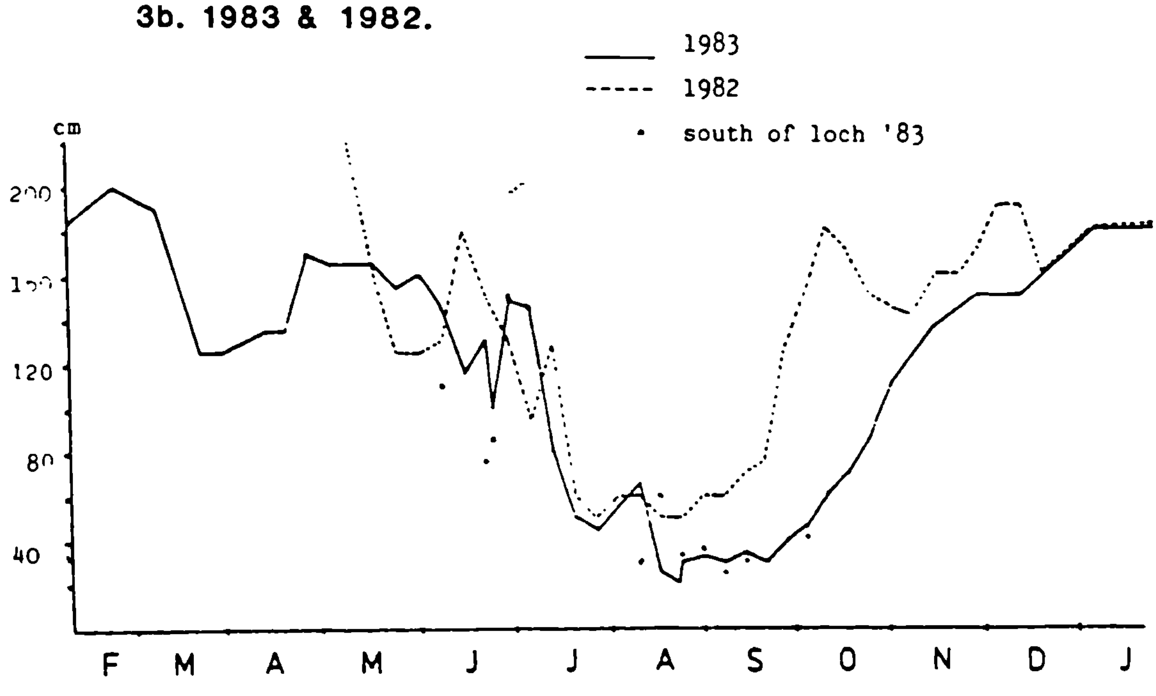


Annex 1. Figure 3 Transparency (Turbidity: secchi disc reading)

3a. 1984.

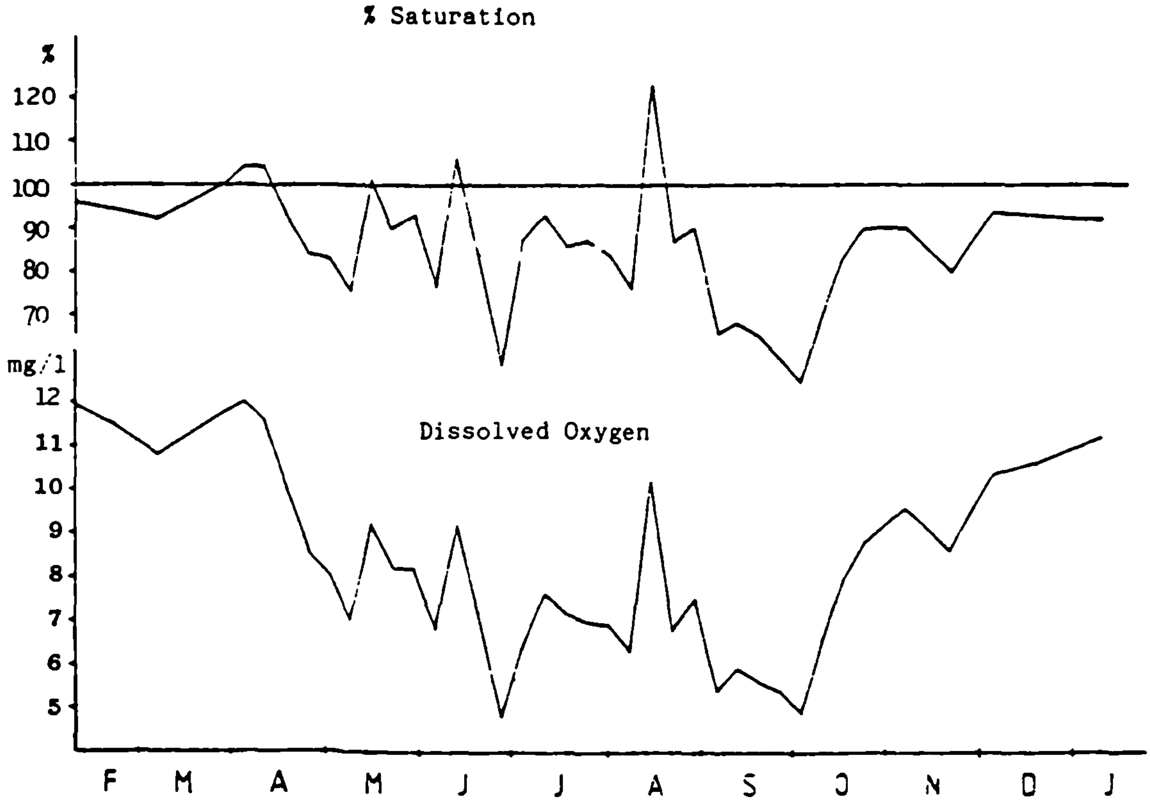


3b. 1983 & 1982.

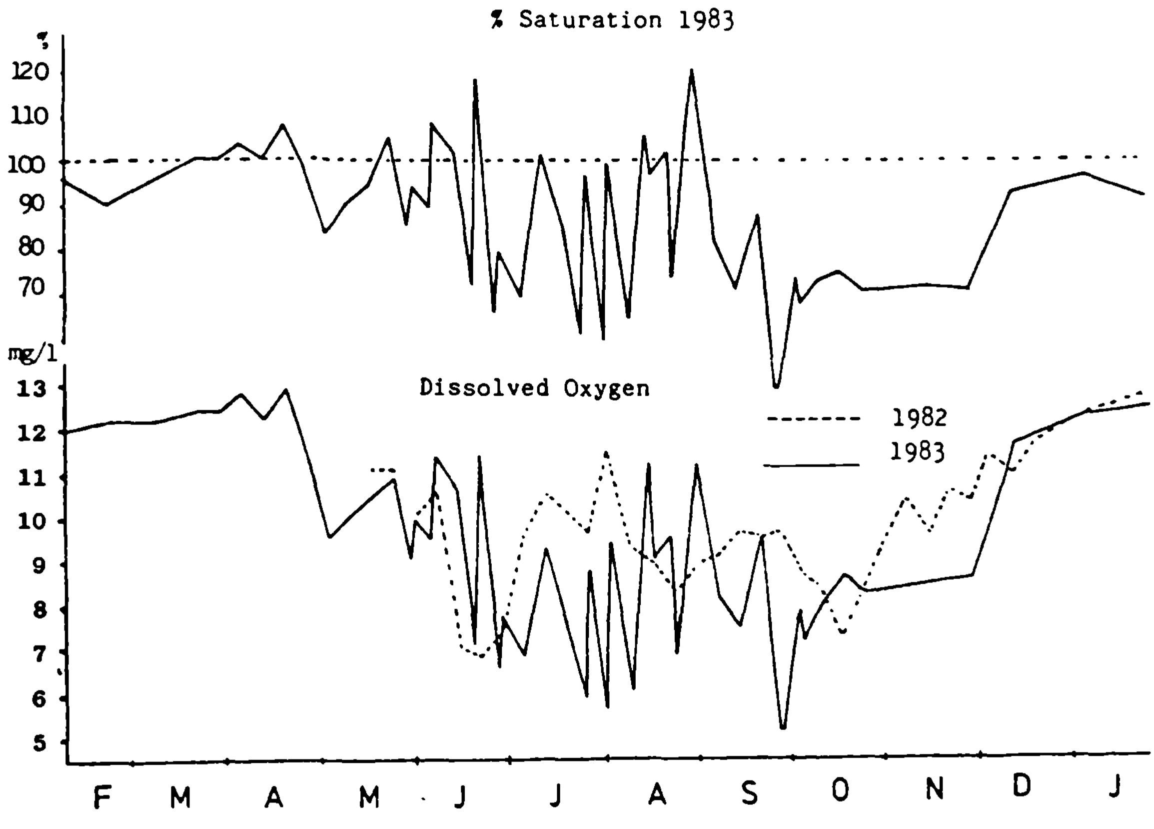


Annex 1. Figure 4 Dissolved Oxygen

4a. Loch levels 1984.

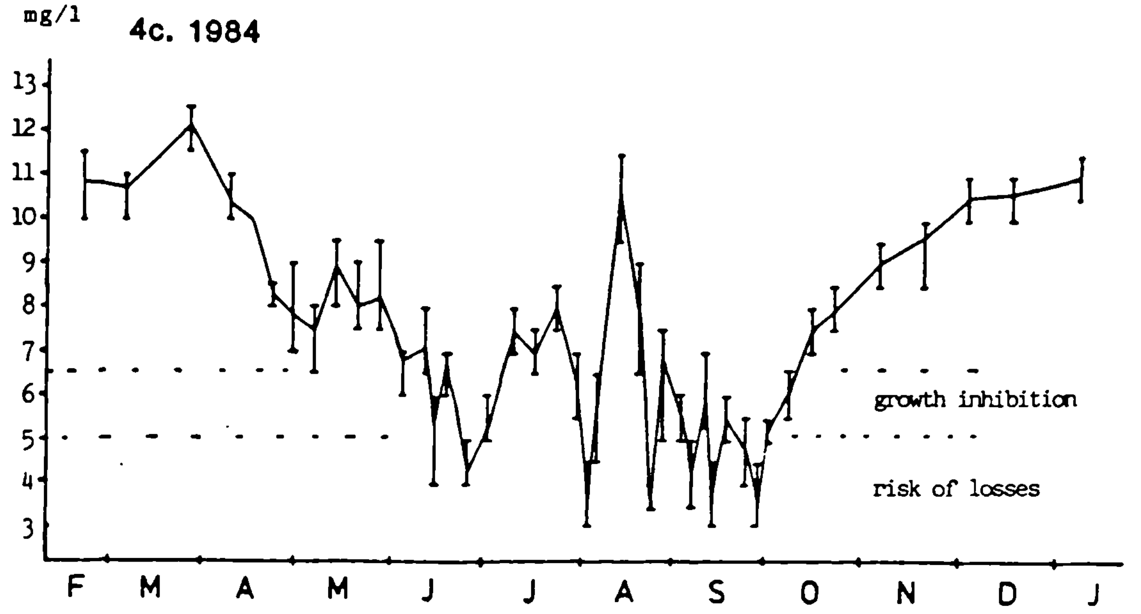


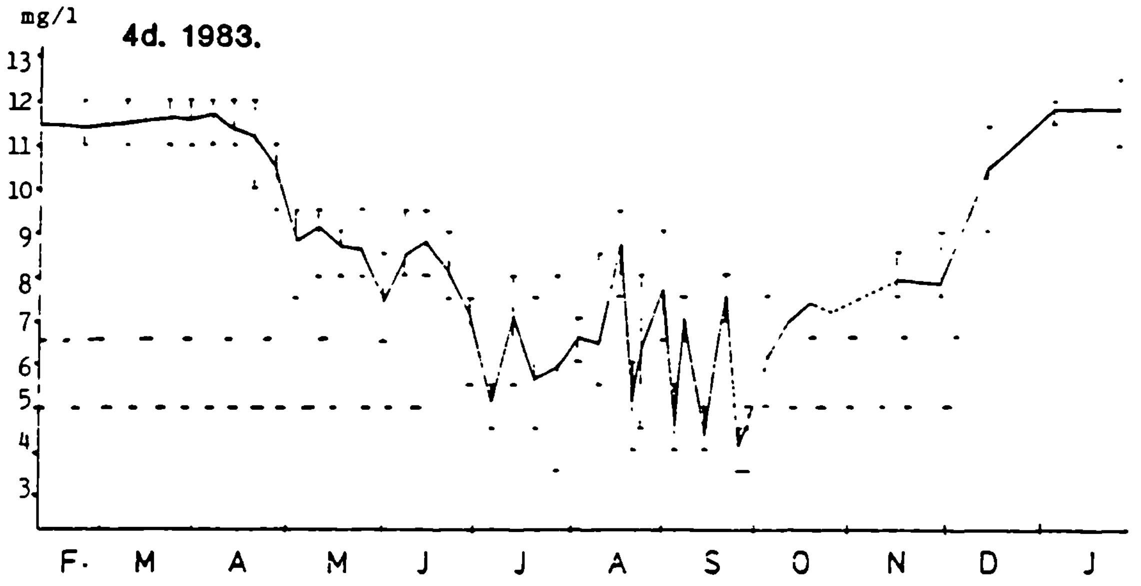
4b. Loch levels 1983 & 1982.

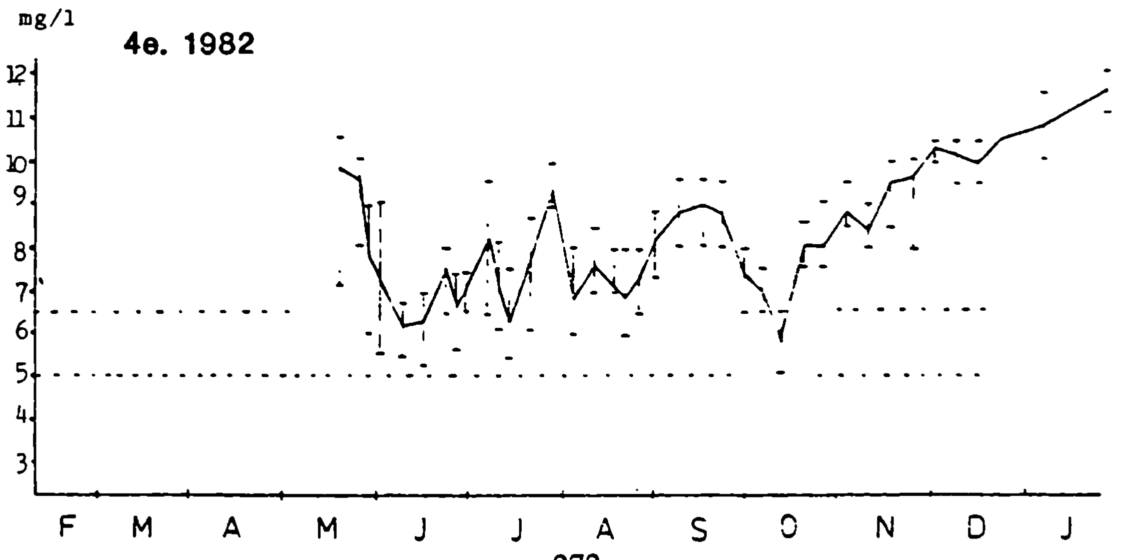


Annex 1. **Figure 4 (continued)** **Dissolved Oxygen**

Cage levels. 24 hour average maximum & minimum.







Annex 1. Figure 4 (continued) Dissolved Oxygen

mg/l

4f. Summer cage levels.

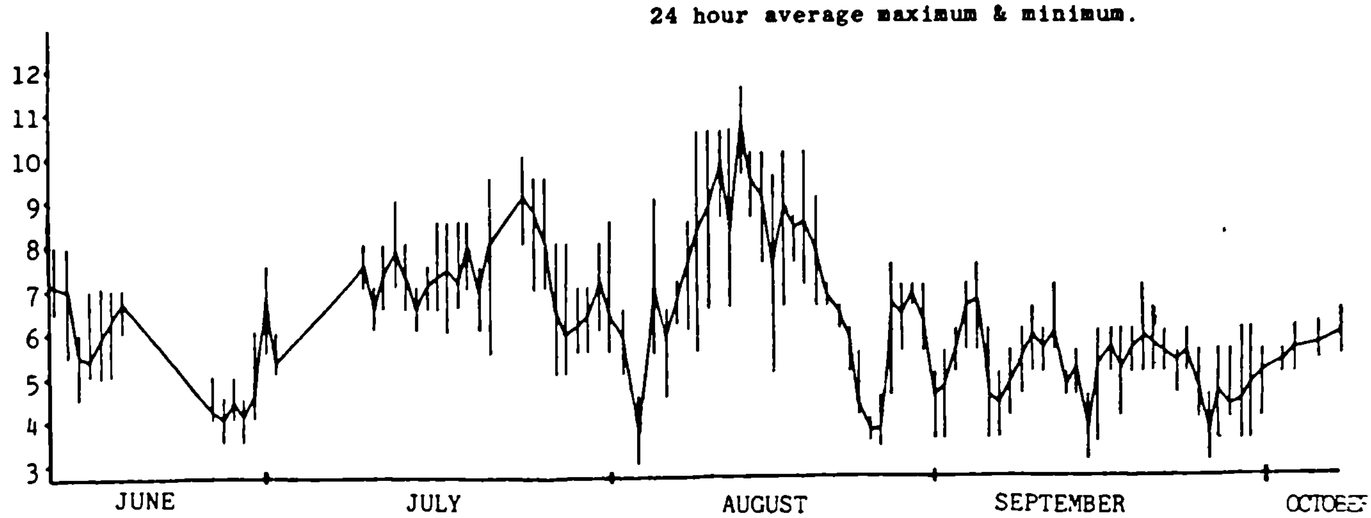
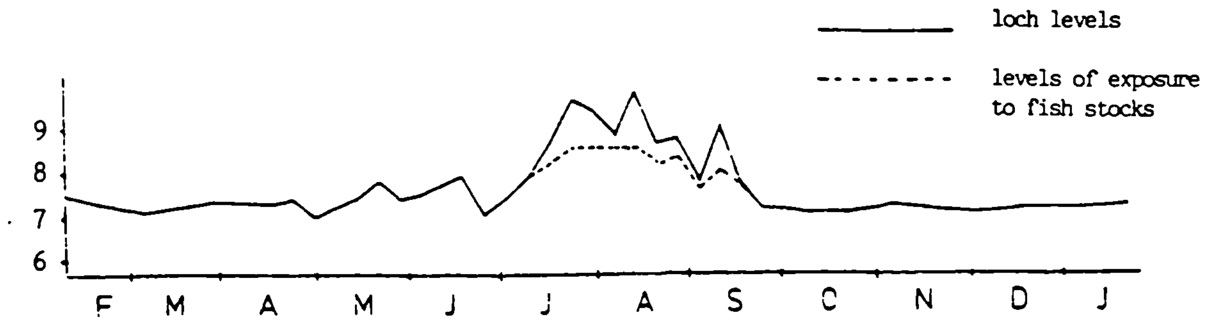
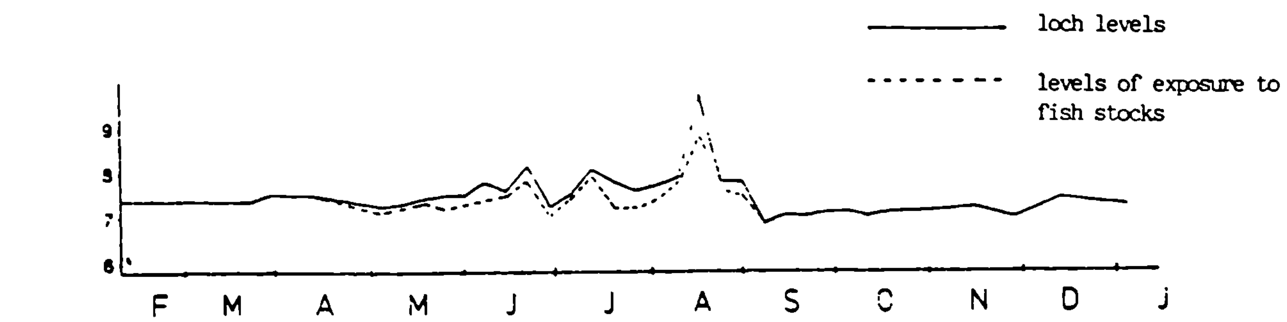


Figure 5 PH.

5a. 1984.

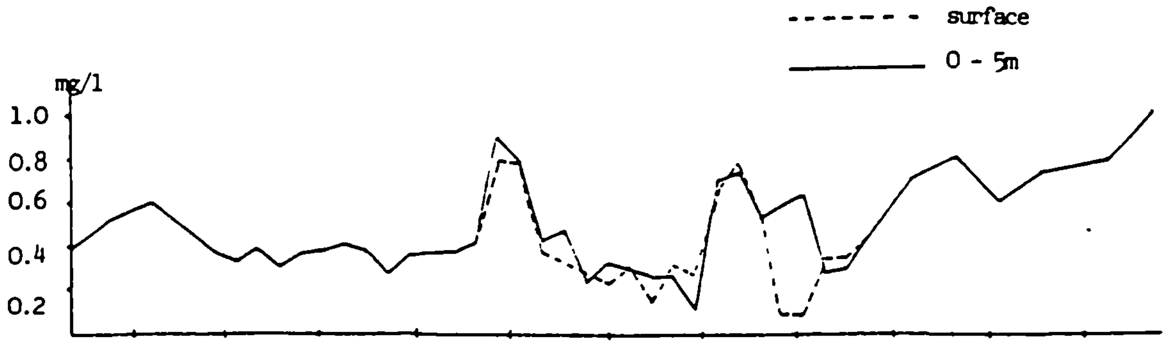


5b. 1983

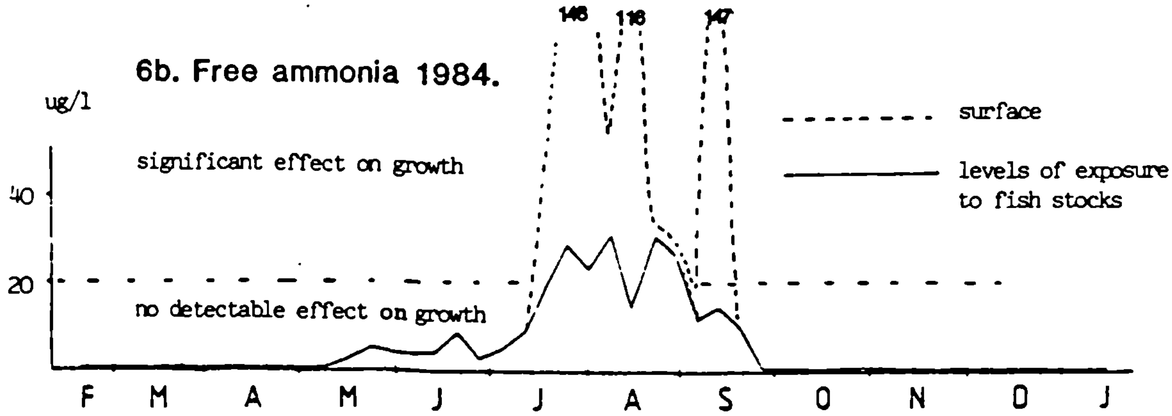


Annex 1. Figure 6 **Ammonia**

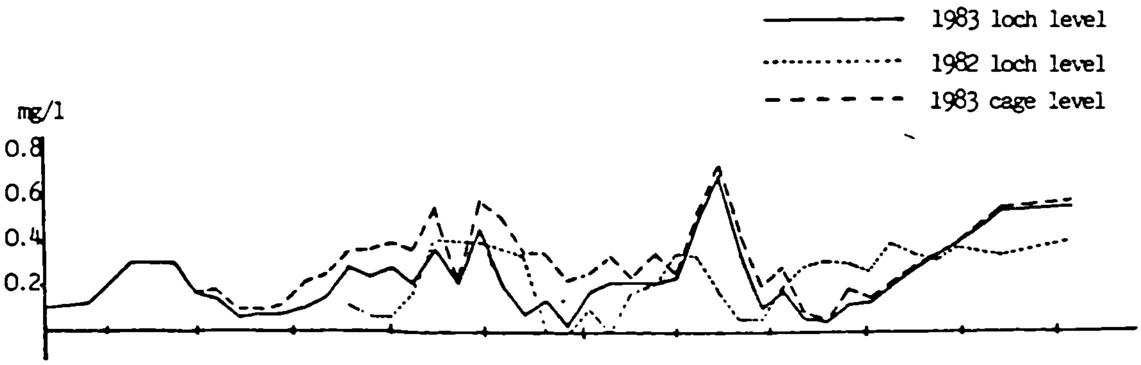
6a. Total ammonia. 1984



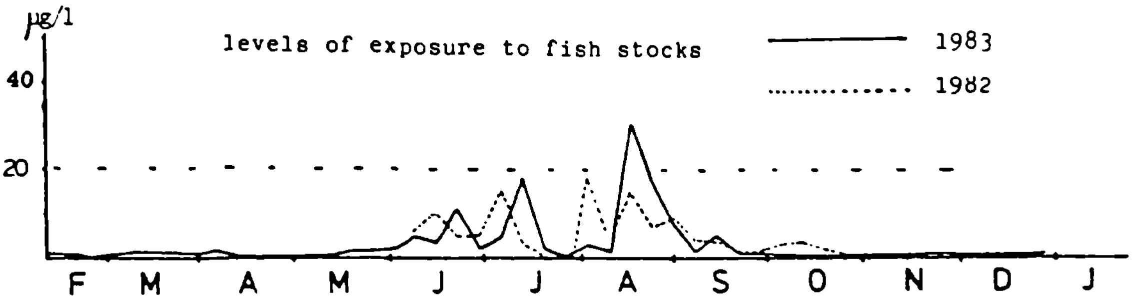
6b. Free ammonia 1984.



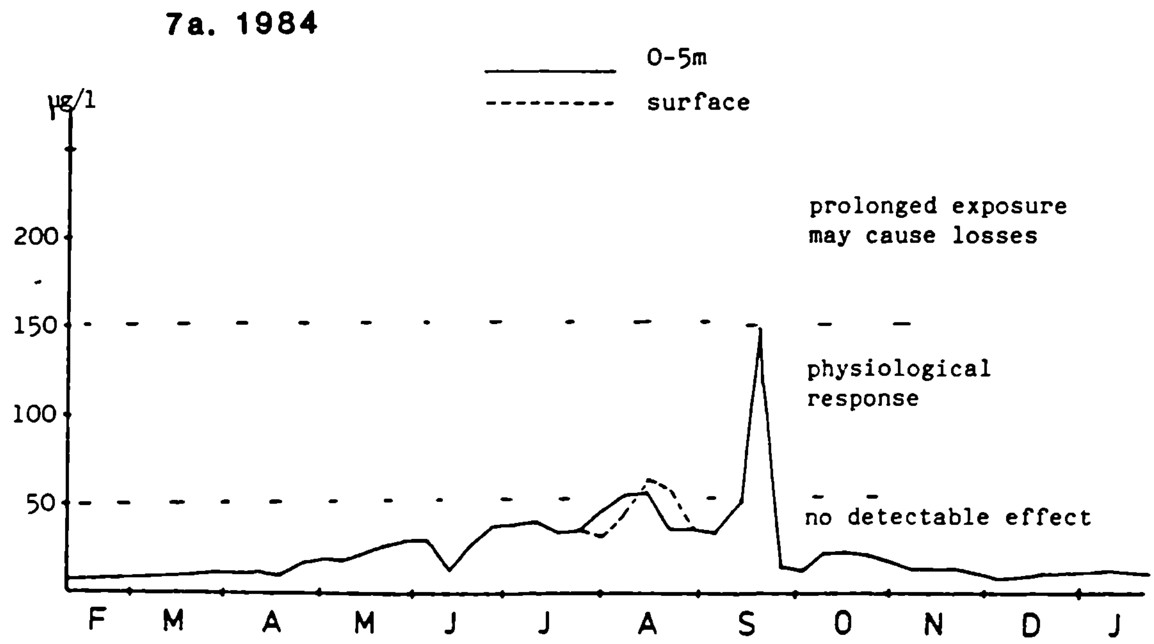
6c. Total ammonia 1983 & 1982.

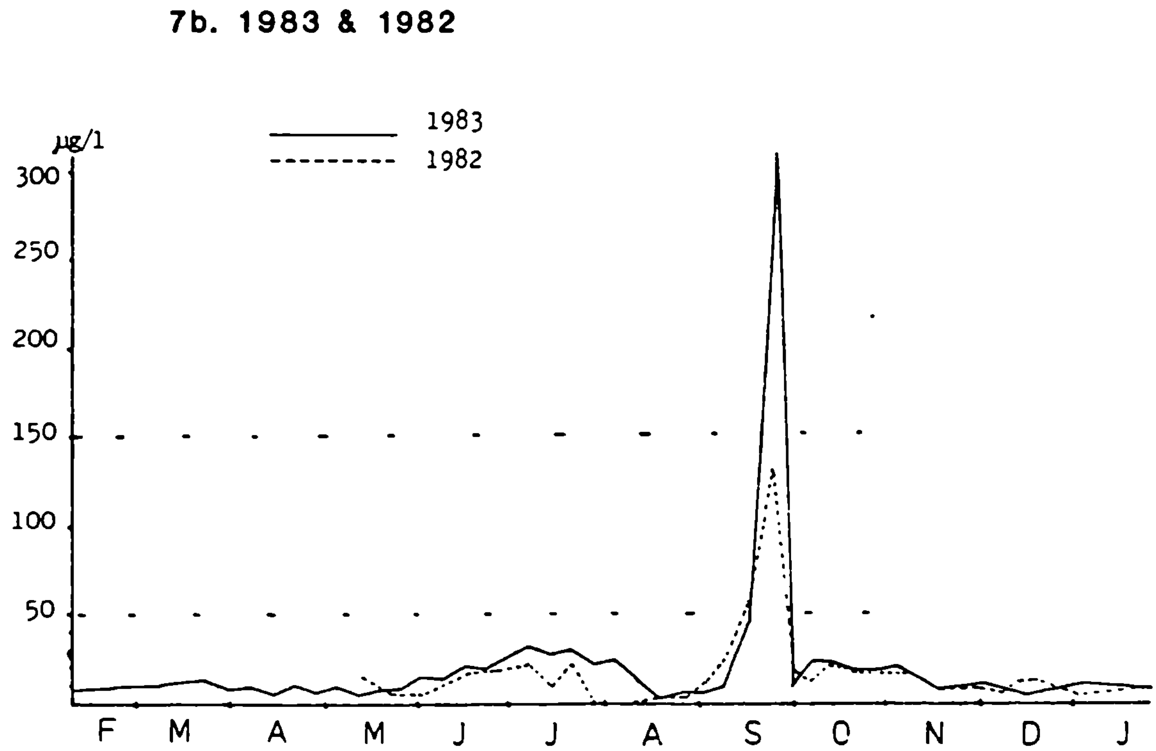


6d. Free ammonia 1983 & 1982.



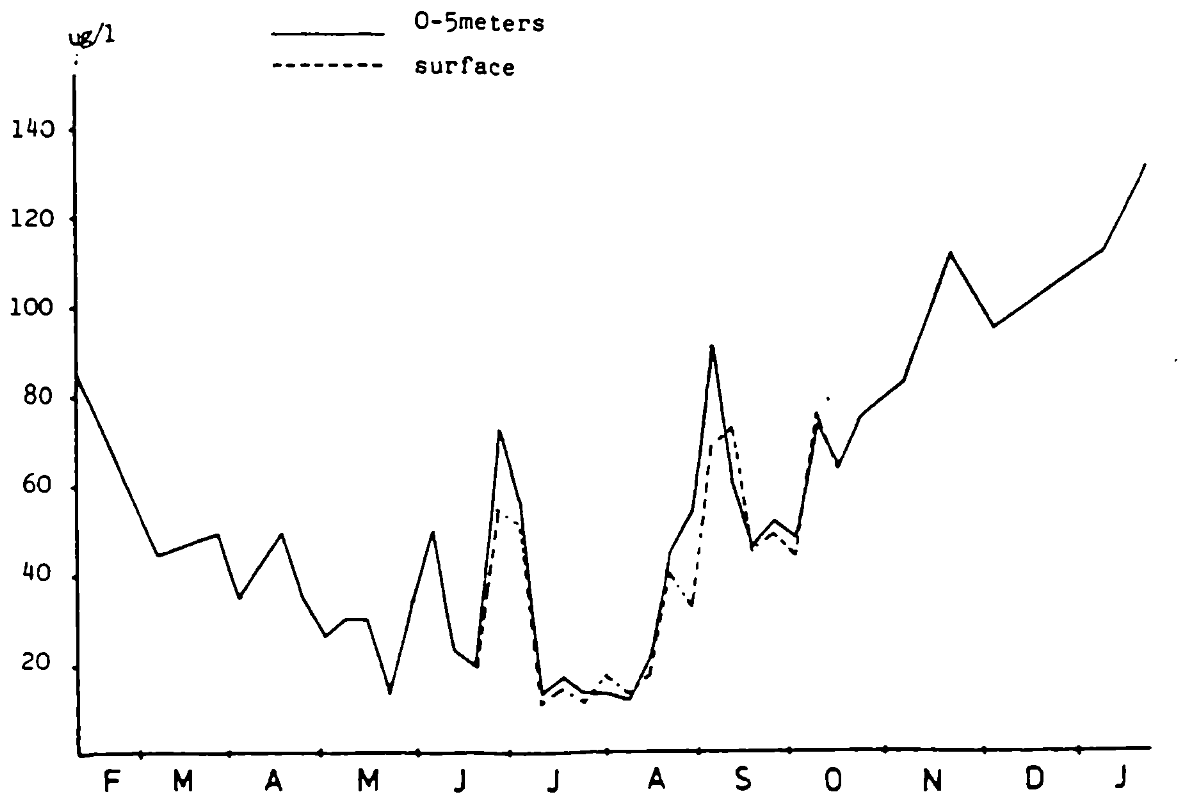
Annex 1. Figure 7 **Nitrite**



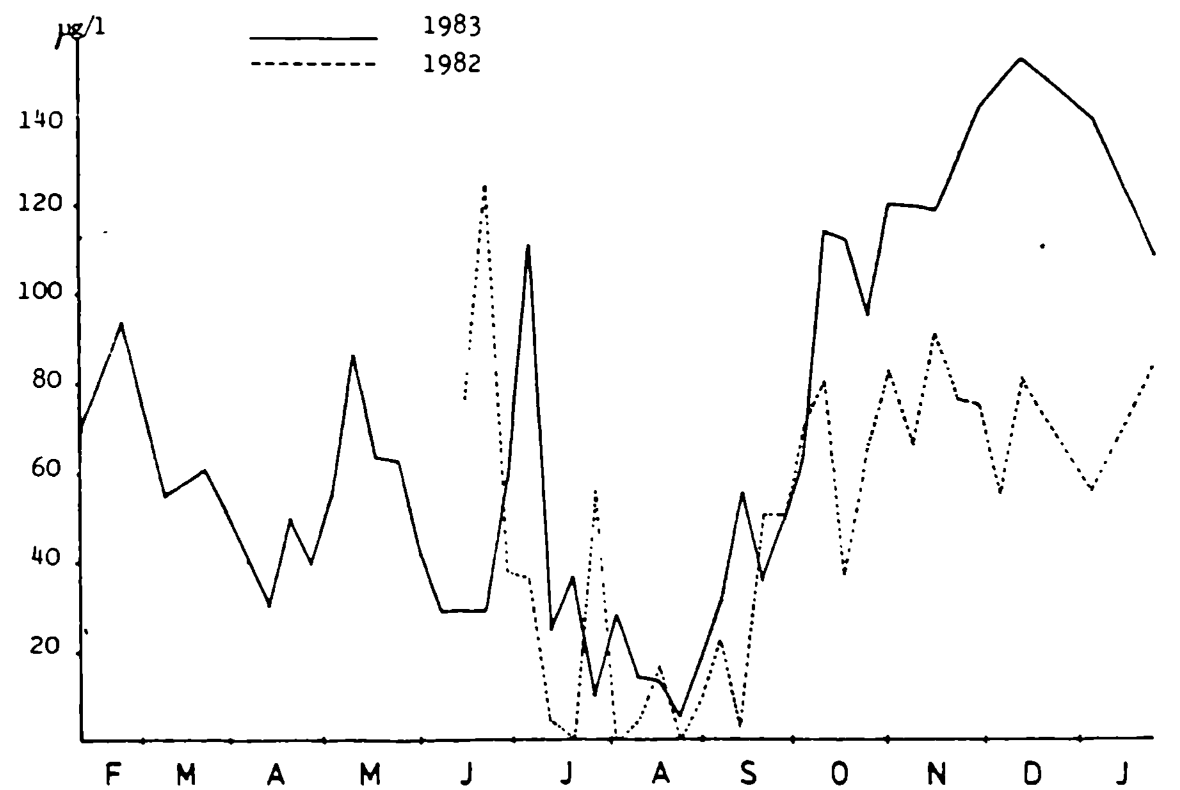


Annex 1. Figure 8 Dissolved Phosphorus

8a. 1984



8b 1983 & 1982.



Annex 2 Methods for the Financial and energy analysis of aquaculture production systems.

This consists of four parts: a description of the model; the financial analysis; the energy analysis and a glossary.

A2.1 The spread sheet model.

To illustrate the methodology of this analysis, one case study, intensive salmon culture in cages, will be described in detail in Annex 4. Other case studies follow the same basic structure, although minor variations in data inputs and analysis occur where required by variations in the culture system. The spreadsheet print-out consist of the following general headings (described in detail below):

Spread-sheet structure:

Heading	Print-out page	Contents
"Outline specifications"	1	(some key input parameters for the operation of the system)
"Capital inputs"	2 &3	(items, components, financial cost, lifetime, materials, specific GER of materials, GER of components, total annual GER, allowance for renewal of capital items(for NPV calculation)
"Operating inputs"	4	(items, cost, specific GER, GER of items)
"Outputs"	4	(product, value)
"Summary and analysis"	5	(totals for inputs and outputs, NPV, IRR, unit financial and energy costs)

Outline specifications. (Spread sheet print-out, page 1)
Each case study has an introductory listing of "specifications".
These specifications include some of the major production variables, either as input values, or as values derived from input values. Some of these (market price, survival,

harvest weight, FCR) can be varied for sensitivity analysis of the model. Specifications which involve a change in the overall systems requirement (eg, annual production) cannot be changed without manually adjusting the inputs of capital and operation items. Specific details vary with the culture system being examined, but generally this section includes:

Production details

-Annual production,

-Market price

-Mean weight at harvest (harvest weight),

-Stock survival rates,

-Stock requirement and harvest numbers (calculated from the above items)

-Feed conversion rates.

Financial variables;

-Discount rate, r_d; This figure applies only to the NPV calculations, and for the purposes of this study can be considered simply as the opportunity cost of capital. The rate chosen will depend on the opportunity cost perceived by the investor. (It can also be influenced by the perceived risk as determined by the sensitivity analysis of the investment proposal; the greater the risks, the higher the returns required in the Base case to allow for fluctuations in performance). In this study, the discount rate in the base cases is taken at 15%. This is higher than the interest rate assumed below, allowing for the risk associated with the investment.

-Interest rate (real), r_i; For simplicity it is assumed that all capital for the case study operations is borrowed (although this figure could be taken to represent a basic opportunity cost applied to investors capital). The allocation of interest as a cost of production applies only to the calculation of unit production costs in this analysis.

- Grant. For the financial analysis the influence of grant aid, where applicable.

-Corporation tax is assumed at 40% unless otherwise stated.

-Sensitivity multipliers. These are multipliers which act on the capital and operating costs and GER values, to allow quick evaluation of the sensitivity of the operation to margins of error in the calculation of the input requirements. These multipliers do not change the material inputs and should be set at 1 when a final print-out of the model is required.

A2.2 Financial analysis

A2.2.1 Cost of production.

This section provides systems of notation for financial costs, and cost allocations for the life of the operation. These costs include capital and operating costs, and cost of finance.

i. Capital Inputs (Financial)

These are identified as follows:

		units	
Item Class	i		
Component of class	ij		
Number of items	n		
Cost per component/item	C_{ij}	{£,$}	
Life of component	T_{ij}	{y}, years.	
Total cost of n components of class	$C_{ij}n$	{£}	1*
Annual depreciation of component	$C_{ij}n/T_{ij}$	{£/y}	2*
Total investment year t	$C_t = \Sigma C_{ij}n$	{£}	3*
Total annual depreciation	$C_a = \Sigma C_{ij}n/T_{ij}$	{£/y}	4*

* Spreadsheet location

1*	Column H
2*	Column J
3*	For t=o, initial investment, cell H83
4*	Cell J84, straight line

Financial analysis requires two procedures for the allocation of capital costs, using the above notations C_t and C_a.

C_t This represents the actual capital expenditure in any year, t, required for calculating NPV, where the timing of the expenditure in relation to income is of major importance. C_t includes the initial capital investment plus replacement of items during the life of the project. The model therefor calculates additional investment based on the lifetime, T, of capital items, which links with the discounted cash flow calculations

C_a This represents the annual capital depreciation of capital items, and is used in the allocation of costs for profit and loss, unit production cost and calculation of tax payments applied in the NPV calculation.

ii Operating or variable inputs (Financial)

These are identified as follows:

Item	i	
Quantity of item	f^*_i	(units specified)
Cost per unit of item	V_i	{£/kg, £/item}
Total cost of item	$V_i f^*_i$	{£}
Total operating costs, V_a = (per year, steady state)	$\sum V_i f^*_i$	{£}

iii Cost of finance

This represents the interest (or opportunity cost) applied to investment and and working capital, calculated as a percentage of the total investment per annum. In the case of working capital, the period of investment will depend on the length of the production cycle. In some tropical production systems, this can be less than 6 months, while in temperate aquaculture it can be more than two years. Unless otherwise stated, it is assumed that on average the investment in stock has a one year turnover i.e. the interest is calculated as a percentage of total annual operating costs. In the case of intensive salmon production the production cycle varies from about 14 months to a maximum of 30 months (suggesting a greater period of investment of working capital), However, the greatest investment, in terms of fish feed, occurs towards the end of the cycle. For salmon culture, an average of one year turnover in investment is assumed in the base case.

The annual cost of capital, $I_a = I_c + I_v$

where:

I_c, interest on investment capital $= r_i C_a$

I_v, interest on working capital $= r_i C_v X$

r_i = interest rate, per annum.

X = conversion factor relating working capital requirements to production cycle

iv Total annual production costs (T_a) (Financial)

This figure represents total costs for the fully operational steady state production. i.e. Capital depreciation + Operating costs +Interest.

$$T_a = C_a + V_a + I_a \qquad \{£/y\}$$

A2.2.2 Outputs (Financial)

i Production

Total annual production	P	(steady state, {t or kg}
Market price of product	p	(For salmon there are two prices, to allow for grilse and salmon) {£,$ etc}
Revenue from sale product, R_a = (average annual)	Pp	{£/y}

ii Performance indicators

Net returns (average annual) (to investment, labour, etc for a steady state production)	$R_a - T_a$	{£/y}
Return on investment	$(R_a - T_a)*100/T_a$	{%}
Unit production costs, T_p=	T_a/P	{£/y} Total costs/Production

Note. It may take several years for a new fish farming operation to reach the full production capacity, or "steady state production". This initial period is referred to as the "build-up". Where there is a slow build-up period, the average production per year (based on Ten years output) will be less than the steady state output. In some cases the average operation costs over ten years will also be less than the steady state costs. In the calculation of unit production costs, the case studies present a figure based on the Steady state production costs and revenues, and also gives that for the average production over a Ten year operational period.
(see text at end document)

Net Present Value (NPV)

NPV is the sum of the discounted cash flows for the life of the operation. In these models, unless otherwise specified, a 10 year life is assumed. Annual depreciation, Ca, is used only in the calculation of Tax payments. Interest on capital is not included here as the discount rate reflects this component of costs.

Cash Flow for each year,

$F_t = R_t - C_t - V_t$ (+grant aid, -tax, where applicable)

where R_t, Revenue
C_t, capital expenditure
V_t, operating expenditure

Discounted Cash Flow , D_t = $F_t/(1+r_d)^t$

where r_d = discount rate

t = year of operation

$NPV = \sum D_t$

Internal Rate of Return, IRR

This represents the Discount rate, r_d, at which the NPV is zero, therefore giving an indication of the return on investment that is achieved in the model operation.

A2.3 Energy analysis.

The energy modelling presented here involves specifying the energy worth of inputs to determine the energy cost of outputs. This is given in terms of the Gross Energy Requirement (GER), which represents all the commercial energy sequestered in the production or manufacture of an item, or the provision of a fuel or service (see glossary, A2.4).

The energy conversion values (or GER) applied to the inputs specified in Case Studies (materials, fuels, services, labour) are derived from the available literature. A list of these values, sources and explanatory notes is presented in Annex 3. This section provides notation for energy input allocations.

GER, lower case symbols, not primed	m	(manufacture, here for capital items) {Joules}
	f	(operating inputs -fuels, feed, stock, services)
Specific GER materials,fuels, services (primed lower case)	m',f'	(e.g. Joules/kg, Joules/l)
Quantities of materials fuels and services (star, lower case)	m* f*	(eg kg steel) (l fuel,days labour, etc)

Thus the GER for each component material,

$$m = m'm^*$$

A2.3.1 **Capital Inputs** (Energy analysis, m for manufacture).

The energy cost of capital items is determined by the energy required for manufacture and the cost of transportation and installation at the operating site. Transport is considered as a separate item, where not included in the GER of manufacture. Capital items are identified as follows:

As for financial analysis:-

Item Class	i	
Component in class	ij	(specifications given)
No. components	n_{ij}	(units specified)
Life of component	T_{ij}	(year)
Materials of components	k	(identifier, e.g. k=2 for steel)

GER for all materials (k) in a single component (ij),

$$m_{ij} = \sum m'_{ijk}\, m^*_k$$

Total for each component $= m_{ij}n_{ij}$

Annual GER allocated per component $= m_{ij}n_{ij}/T_{ij}$

Total Annual GER for capital items $m_a = \sum m_{ij}n_{ij}/T_{ij}$

Transport.

The assumption made in the calculation of the GER of transport of capital goods are given in Annex 3, note 15. In the spread sheet model, the total weight of capital items delivered to site, divided by the life of these items, gives an annual delivered weight of capital goods which can be attributed to the annual production. (This does not include buildings or concrete for a slipway as transport is assumed to be included in the GER values used for these items). The transport distance km, and the GER of transport (MJ/t km), are included as variables, from which the total GER of transport is derived.

A2.3.2 **Operating inputs.**

This is a more simple process than the above.

Identifiers are as follows:

Item	i	
Quantity of items	f^*_i	{t,kg,l,days,km}
GER per unit of item	f'_i	{MJ per t,l,etc}
Total GER per item, $f_i =$	$f'_i f^*_i$	{MJ}

Total GER for operating inputs (average annual)

$$f_a = \sum f_i$$

Transport is included as an Item ,i. Transport of feed and stock is calculated on the delivered weight of input materials, at a unit GER of 4MJ/(t km) (See Annex 3, note 15).

Total annual average GER, for the steady state production

$$GER.T_a = ma + f_a$$

Capital + Operating

(average annual figures)

A2.3.3 Outputs

Here we are interested in the (average) annual output over the life of the operation, P_a. Units are generally kg or tonnes whole wet weight.

Then the GER per unit output = $GERT_a/P_a$ (Cell I164)

This figure is given in MJ/kg product whole, wet weight; edible product and edible protein. For comparison with other production systems and products the units can be changed to the appropriate form for the analysis required (eg MJ/ unit food energy, etc).

Build-up period: Where the species cultured has a life cycle longer than 1 year, there will be a lag period from going into business and reaching the steady state output. This means that the average annual output over the life of the operation, against which capital inputs can be allocated, will be less than the steady state output. In the case of salmon farming, with a ten year life, the average annual production (175t p.a.) is 12.5% less than the steady state output of 200t. For operations with a production cycle of one year or less, the only lag in reaching the forecasted steady state output is likely to be due initial production problems resulting in a learning period when poorer performance occurs.

Annex 2. Table 1. Glossary for financial and energy models

Units

t	tonnes
g	kilograms

General Functions and names

GER	gross energy requirement
NPV	net present value (of investment)
IRR	internal rate of return

Identifiers in spread-sheet models

i	input item or item class
ij	input component of item class
n	number of items or components
k	material of components, numerical identifier. e.g. 2 = kg steel.
T_{ij}	Life of component

Financial analysis

C	capital inputs
C_{ij}	cost of capital component/item
C_t	total capital inputs in year t
C_a	total annual depreciation of capital inputs
V	operating or variable inputs
V_i	cost of operating item
V_a	total operating costs
f^*_i	quantity of operating inputs
I	interest charges
I_c	interest on investment capital
I_v	interest on working (operating) capital
$_{I}a$	total annual interest charges
r_d	discount rate
r_i	interest rate
T_a	total annual production costs, steady state output
T_p	Unit production costs, steady state output
T_m	Unit production cost, mean over life of operation
P	total annual production {t, kg}
p	market price per unit production { £/kg, $/kg etc}
R	revenue
R_a	annual revenues, steady state output
R_t	annual revenue, year t
R_m	annual revenues, mean over system life. (sum R_t)/tmax
F	cash flow
F_t	cash flow year t
D_t	discounted cash flow, year t

Annex 3 Energy conversion values applied to case studies

1 Introduction.

The energy modelling presented here involves specifying the energy worth of inputs to determine the energy cost of outputs. This is given in terms of the Gross Energy Requirement (GER), which represents all the commercial energy sequestered in the production or manufacture of an item (see glossary).

The energy conversion values (or GER) applied to the inputs used in Case Studies are derived from the available literature. In most cases there are considerable variations in the GER for given items, depending on the processes used and the system boundaries applied to the analysis of the process.

These notes present GER values in the literature, and the values chosen for the case studies, usually the mean value of available data. The significance of these GER conversion values are tested, where appropriate, in the sensitivity analysis of the case studies. The following notes refer to general material inputs applied to all the models, and discusses the issues surrounding the GER values of certain major inputs These are summariesed in Table 1 .

Annex 3. Table 1 Summary of Energy Conversion Values used in Case Studies (see following notes)

Note	Item	Units	GER MJ per unit		References
	(material Fuel, Service).	Case	Case Studies	Literature	
2	Steel, raw, sheet kg		22-78		12,14,15,16,17
	Manufactured		85	85-9	13,14
	Vehicles	kg	85	86	8,12
	Agricultural machinery	hr	500	280-710	2
	Maintenance Vehicles	% capital	6%	6%	8
	Aluminium	kg	320	260-380	16
3	Plastics	kg			
	PVC		130	70-180	2,12,16,17
	P-ethylene		105	50-159(813)	12,15,16,17
	P-propylene		125	95-155	12,15,16
	P-styrene		87	62-113 12,15,16	
	P-styrene foam) P-Urethane)		144	138-150	16
	Nylon		175	66-285	2,15,16,17
	GRP (Glass Reinforced Plastic		80	See text	
4	Buildings	m^2 area	1200	1207-2266	16, see text.
5	Concrete	kg	0.92	0.07-1.77	16
	equivalent to-----	m^3	2760		
	Reinforced concrete	kg	8	2.5-14	16, 17
	equivalent to-----	m^3	24000		
6	Earth moving				
	-by machine per	m^3	23	16-29 2	
	-by machine per	hr	500	280-710	2
	-by manpower	man-day	13		see text
7	Timber, bamboo (as timber)	kg	9	3-13	16, 17
Operating inputs					
8	Feeds and Fertilisers				
9	Intensive fish culture				
10	Trash fish (landed)	kg	20	3-56	2
11	Salmonid feeds (dry pellets)	kg	40	25-72	2,3 See text
12	Semi-intensive fish culture				
	Agricultural byproducts				
	e.g. Rice bran	kg	4	4.2	2
	maize bran	kg	4	--	--

Annex 3 Table 1 (continued)
Summary of Energy Conversion Values used in Case Studies

Note	Item	Units	GER MJ per unit		References
	(material Fuel, Service).	Case	Case Studies	Literature	
13	Fertilisers				
	Nitrogen	kg	80	80	2,8,12,
	Phosphorus	kg	14	12-20	1,2,8,12,13,
	Potassium	kg	9	9	9,12
	N-P-K	kg	30	30	2
	Lime	kg	10	10	16
	Animal manures	kg	0	0	
	Vegetable byproducts	kg	0	0	
14	Stock		see notes for specific Case Studies		
15	Transport, Road	t km	4	4	12
16	Labour	day	0,13	0,12-18	6,8,9,13,14
17	Fuel and power				
	Petrol	l	40	40-46	5,6,8,12,13
	Diesel	l	40	38-45	6,12,13,14
	Electricity	KWh	9	3.6-14.4	2,5,6,12,13,16
18	Pharmaceutical and chemicals				
	Insecticides)				
	Herbicides)	kg	100	95-102	8,12,13
	Antibiotics, chemical	kg	100	-	-
19	Packing and marketing.				
	Packing		See text		
	Ice (flake)	kg	0.94	0.94	9
20	Legal and professional services	See text			
			0	-	-
21	Maintenance facilities				
	and equipment	% capital	2	See text	
	Vehicles				

References
1: Bardach, In Pimentel, 1980; 2: Edwardson, 1976(a). 3: Folke, 1988. 4: Folke and Kautsky, 1989. 5: Watanabe, 1985. 6: Mathews et al, 1976. 7: Mayer and Rawitscher, 1978. 8: Pimmentel et al 1973. 9/10: Rawitscher and Mayer, 1977/1979. 11: Shifa, 1987. 12: Storke, 1978. 13: Kumar and Twidell, 1981. 14: Wiviott and Mathews, 1975. 15: Edwardson, 1976(b). 16: Boustead and Hancock, 1979. 17: Chapman and Roberts, 1983.

Notes

2 Steel and steel products.

This category includes all steel based structures and equipment, motors and motor vehicles. The values quoted in the literature for raw steel and steel products vary considerably. Some of this variation can be attributed to the grade of ore, the use of scrap metal and the material efficiency of the production operations (ref 17). The GER values quoted for raw steel and simple steel products (rods, sheet steel) produced from ore range from 22 to 78 MJ/kg . The GER for manufactured steel products, including boats engines and motor vehicles, ranges from 85 to 90 MJ/kg. The small range in the manufactured item is surprising given the large range in the GER of the raw steel. For the purpose of these evaluations, a GER of 85MJ/kg is used for all steel inputs, including motor vehicles. (The assumption that the whole weight of a motor vehicle is steel, allowing the use of on conversion value directly on the unladen weight has been justified by Boustead and Hancock, 1979.)

The use of stainless steel and galvanised products is ignored. Stainless steel is used in small quantities for specialised items of equipment. The difference between the above GER of steel products (85MJ/kg) and the quoted GER of 115MJ/kg stainless steel (ref. 17) will have a negligible effect on the final outcome of the analysis. Similarly, galvanising, with an additional GER of 0.5MJ/kg galvanised steel, is negligible in comparison to the variation in the GER of finished steel.

3 Plastics.

A wide range of plastic products are used in fish farming for fish tanks, buoyancy for floating structures, ropes and nets, feeders and other equipment. A wide range of GER values are given in the literature. The mean values calculated are applied to the case studies. No literature was found for GER of GRP (fibre glass). A figure for this item was therefore derived as follows: It is assumed that the ratio of glass fibre to resin is 1:1. The GER of glass from raw materials in the ground is in the range of 20-30MJ/kg (ref. 17). The GER of the polymer resin is assumed to be 100MJ/kg, based on the GER of the above plastic materials. Thus on kg of GRP would have a GER of about 62MJ/kg ((100+25)/2). Allowing an additional 30% for manufacture of the GRP items, the total GER of GRP would be about 80MJ/kg. For the purpose of this model, polyurethane is assumed to have the same GER as polystyrene foam.

4 Buildings.

The type of buildings associated with the development of a fish farm will vary from simple open plan storage and work space to dwellings associated with the provision of on site accommodation for a fish farm manager/worker. The latter is not considered in these models, as this would be an energy cost associated with personnel whether provided by the business or not. The GER of a 2 story house, from raw materials, is quoted at between 1207 and 2266MJ/m^2 (mean approx 1700) (ref. 16). As the fish farm building is in most cases likely to be a more simple single story building, the lower value of 1200MJ/m^2 is used.

5 Concrete.

Apart from that already included in the calculation of the GER of buildings, Concrete is used mainly for the construction of shore landing facilities. The GER of ready mixed concrete ranges from 0.07 MJ/kg - 1.77MJ/kg (mean, 0.92MJ/kg). Assuming 1m^3 concrete weighs approximately 3000kg, using the above mean GER conversion, one cubic meter of concrete will have a GER of 2760MJ. The GER for reinforced concrete is listed at between 2.5 and 14MJ/kg, (mean 8MJ/kg, =24,000MJ/m^3)

6 Earth moving.

This is relevant to any land based fish farm developments, particularly where earth ponds are constructed. The method of earth moving will have a significant effect on the GER value applied. In many developing countries, pond construction will often involve manual or animal labour, while in most other situations earth moving machinery will be used.

Earth moving machinery. The GER of earth moving can be estimated by the volume, in GER per unit volume, or transferred to the number of hours of machine time required, and calculated at an hourly rate. Both methods are used in case studies, depending on the data available. The operating GER for agricultural machinery, (including manufacture and servicing) range from 280MJ/hr to 710MJ/hr. Figures used by Edwardson (1976a) appear to vary depending on the system being analyzed. One estimate of 16.8 MJ/m^3 excavation is based on 710MJ/hr for ploughing/ tractor work. Another author quoted by Edwardson estimates the GER of earthmoving at 29MJ/m^3. (An example of fish pond excavation involves moving 2900m^3/ha, giving a total GER of

85GJ/ha). For this study a mean GER of $23MJ/m^3$ is assumed for earth moving by machine.

Manual excavation. Edwardson (1976a) assumes 5 man-h/m^3 and 1938 man-d/ha for manual excavation. The GER of manual excavation, using a rate of 13MJ/man-d of 8 hours, would therefore be about $8MJ/m^3$. A more conservative estimate for excavation of $1m^3$/man-d (based on Beveridge and Stewart, 1986) is assumed for labour sensitivity analysis in this study, giving a GER of 13 MJ/m^3. In the base case, labour is not included in the GER calculations. The choice of GER of labour is discussed in the main text.

7 Timber, bamboo.

The fuel energy attributed to the harvesting and delivery of timber ranges from 3-7.2 MJ/kg. A GER of 12.6 is given for wood poles. For these Case Studies, a GER of 9MJ/kg is assumed. The same value is attributed to bamboo.

8 Fish feeds and fertilisers: Introduction.

The role of feeds and fertilisers in aquaculture varies depending on the species cultured, and the type of culture system. Intensive culture of most finfish and crustacean requires either a complete formulated diet, usually containing a significant quantity of fish protein, or trash fish used directly as a feed. The role of natural feeding from the aquatic environment is negligible in these operations (except for juveniles of some species, eg shrimp) and fertilisers are not generally used.

At the other extreme, the culture of seaweeds or filter feeding molluscs requires no inputs of feed by the operator, as the growth is achieved from the natural productivity of the culture environment. Similarly, in extensive fish culture, the output depends on natural productivity, with little or no inputs from the operator, except perhaps the input of some fertiliser. In semi-intensive systems, production is achieved from both the productivity of the culture system, and the input of supplementary feeds and fertilisers. The feeds are usually of lower quality than those required in intensive systems, as their function is to increase the food energy available, thus sparing the protein of natural feeds for fish growth. The importance of feeds as a component of the cost and the GER of aquaculture systems can therefore vary widely.

9 Intensive fish culture and the use of fisheries products.

Most intensive fish culture systems rely on feeds which have a significant input of fish protein, either in the form of fresh trash fish, or as fish meal and fish oil incorporated into manufactured diets. The GER of fish feeds in these cases will therefore depend on the GER of the fishery products used in fish diets. Edwardson (1976b) derived GERs for landed fish ranging from 3MJ/kg to 56MJ/kg (weighted mean 23MJ/kg), depending principally on the type of fishery and fishing method, size and type of vessel and the distance from port. For the purposes of this study a GER of 20MJ/kg is assumed for landed fish.

The GER of fish meal, which forms an essential component of manufactured diets, incorporates the GER of landed fish, and the energy associated with the processing and production of the meal. Edwardson (1976a) calculated the GER of fish meal for pelagic (39.6MJ/kg) and demersal (178.5MJ/kg) fish species. The wide variation between these values reflects the differing energy requirements of different fisheries. In determining a realistic GER for the production of fish feeds, it is therefore necessary to know which fishery the fish meal is derived, and examine the GER of that particular product. In practice as fisheries change, and the catch per unit effort changes, the GER of fish products will also change. It is therefore difficult to establish a realistic and widely applicable value to attribute to this component of the fish farming system.

In the case of the European salmonid culture industry, the principal fish meal component of the diet is derived from pelagic fisheries. Therefore in calculating the GER of the Fish feeds, a GER of fish meal is assumed to be 40MJ/kg. The GER of fish oil, as a product of fish meal manufacture, is assumed to have the same GER as the meal of 40MJ/kg.

10 Trash Fish.

Trash fish is often used as a feed for intensive fish culture where there is a ready supply available close to the farming operation. Some examples include intensive culture of Salmon in Norway, Yellowtail in Japan, Grouper in Indonesia. The main disadvantages of fresh diets are associated with their volume, and consequent handling involved, and difficulties with storage and quality. Reasonably fresh material is required. The GER of trash fish is taken as the average for landed fish above, at 20MJ/kg. The true value will depend on the particular type of fishery supplying those fish.

11 Manufactured fish feeds.

The specific composition of manufactured fish feeds will depend on the species for which it is produced, but it is generally the case that these diets have a significant proportion of protein, much of which is derived from fish meal. Here we will consider diets for salmonid culture.

The literature on energy content of fish feeds for Salmonid culture gives a range of values, from 25MJ/kg to 72MJ/kg. A calculation of the GER of a salmonid diet is presented in Table 2. Some of the energy values for ingredients and processing are derived from Edwardson (1976a), who calculated a GER for trout feed of 72MJ/kg. The figure here is considerably lower due to the change in the type of fish meal used: previously both demersal and pelagic fish meal was included in fish feeds, while now pelagic fisheries provide the major input.

For the purposes of this study, the GER of Salmon diets is assumed to be 40MJ/kg. The sensitivity of operations to this value is demonstrated in the Case Studies. Intensive feeds for other species will depend on the specific ingredients. Given the wide potential variation in the GER of salmonid diets depending on the type of fishery providing the fish meal, the degree of accuracy for a particular culture system in this case is of less importance. The case studies serve to illustrate the range of GERs for different aquaculture products and the sensitivity analysis demonstrates the relative importance of the GER of different inputs, in this case fish feeds.

Annex 3. Table 2 Energy costs of manufactured salmon feed

Raw materials	Quantity %	GER MJ/kg	GER Feed MJ/kg	GER Feed %
Herring meal	50.0	40	20.0	50.2%
Fish oil	19.0	40	7.6	19.1%
Soya meal	9.5	16	1.5	3.8%
Whole wheat	14.0	10	1.4	3.5%
Blood meal	5.0	12	0.6	1.5%
Nutrient premix	2.5	350	8.8	21.9%
			------	------
Total			40	100%

Note: GER of fish meal derived from *
Pelagic fishery 40 MJ/kg Demersal fishery 179 MJ/kg

*Edwardson 1976 (b).

12 Semi intensive culture systems (use of agricultural byproducts)

These are systems where the natural productivity of fish feeds in the culture environment is encouraged by the addition of fertilisers (organic and inorganic) and supplemented by the addition of feeds. Supplementary feeds vary greatly in quality, depending on the relative role they play in the total diet of the fish. In semi-intensive shrimp culture, for example, fertilisation of the pond is usually limit to an initial fertilisation prior to stocking, and the feeds used represent a complete diet of high quality.

Semi-intensive carp or tilapia culture, on the other hand, rely on relatively large inputs of fertilisers (manures, plant material, in some cases inorganic) stimulating natural productivity in the pond, supplementing this source of fish feed with low grade inputs such as rice bran, mustard seed cake, maize bran. There are problems in trying to attribute values to many of these items, either in energy or cash terms; these fish farming operations often represent part of an integrated farming system, where pond inputs represent byproducts of other activities recycled within the farming system. They may have no defined cash value as they are not traded, but they do still represent a valuable and limited resource (see text in Chapter 6).

13 Supplementary feeds

In determining the internally transferred cash value, some products can be given a market value, such as rice or maize bran. The GER of these items are more difficult to determine. As they are by- products, should they take an energy value corresponding to that of the finished maize product? Alternatively, should zero energy cost be assumed, as byproducts with limited other uses? Edwardson (1976a) attributes no energy cost to wheat and maize wastes used in integrated duck - fish culture. However, in the case of rice bran used in Asian fish culture systems, a GER of 4.2MJ/kg was applied. As long as there are alternative and potentially competing uses for agricultural by-products, then there is a value associated with these alternative uses.

In the case of smallholder fish farming operations in Malawi (see Chapter 7), madea was reported by some farmers to have limited other uses, and fish farming was cited as a useful way of improving the use of this resource. However, this by-product can be used as a supplementary feed for free range poultry, and for human consumption in times of food shortage. In the base case of the energy analysis of smallholder tilapia production, the energy cost of Madea is assumed to be equivalent to that calculated for rice bran by Edwardson (1976a) at 4.2MJ/kg. The effect of zero energy cost for this input is demonstrated.

14 Fertilisers.

a) **Inorganic:** The GER of inorganic fertilisers is well documented in the literature. Values used in this study are detailed in Table 1.

b) **Organic:** The value of organic material is considerably more difficult to quantify. **Animal manures:** In previous studies of GER manure has been attributed zero value. Although a byproduct of livestock production, perhaps without a specific financial value, it is often a limited and valuable resource in small farming operations. Similarly, although energy may be involved in it's production, it is difficult to attribute a proportion of the GER embodied in the livestock which produced it. Where that livestock is produced extensively, the GER is likely to be low. If, however, livestock feeds were involved, a much higher GER would be attributed to the animal products. In some intensive operations, where large volumes of solid wastes are produced, financial and energy costs could be associated with the disposal of these byproducts. For the purpose of this study, the GER of manure is assumed to be zero. The implications of this on the evaluation of aquaculture system is discussed in the text.

Vegetable byproducts: As with animal manures, vegetable byproducts are valuable sources of organic matter for the farming system, but it is difficult to quantify in cash or energy terms. No energy cost is attributed to these items here.

15 Stock

The GER of stock will be determined by the culture or fishing processes required to produce and deliver those stocks to the fish farm operation. These will be considered in specific case studies. In the case of salmon farming, the GER of smolts is calculated from a full analysis of the smolt production system, by the application of the model developed here (Stewart, unpublished).

16 Transport.

It is assumed that all transport of capital and operating inputs is by road. The GER of transport is assumed to be 4MJ/t km (ref. 12). The distance of transport required is stated for each case study. The transport of capital items and operating inputs are considered separately.

Capital items: The GER of transport of capital items is based on the weight of delivered items divided by their life, giving an annual delivered weight attributed to production.

Operating inputs: In most cases only feed and stock are included in the operating transport, as other items are likely to be insignificant (and the running of the farm vehicle will allow for minor transport items).

17 Labour.

The choice of energy value attributable to labour is controversial. here no energy cost is attributed to labour in the base case. The impact of applying metabolic and standard of living related energy costs are demonstrated in the analyses (see main text).

18 Fuel and Power.

Conversion values for oil based fuels and electricity are well documented.
Fuels: These consist of petroleum for the running of outboard motors and vehicles and small generators, and diesel for larger boats. The GER for petrol and diesel quoted in the literature range from 40-46MJ/l and 38-45MJ/l respectively. Here it is assumed that both fuels have a GER of 40MJ/l.

Electricity: The GER of electricity will depend on the generating process involved. Figures in the literature studied range from 3.6 to 14.4MJ/KWh. The lower figure represents the delivered energy, and as such does not incorporate the full GER required to provide that power. The efficiency of production varies with the generating process: eg: 80% for hydro, 27.5% for thermal. This would give a true GERs of 4.5MJ/KWh and 13.1MJ/KWh for these generating processes respectively. For this study a GER for electricity is taken to be 9MJ/KWh.

19 Pharmaceutical and chemicals

This category of items includes antibiotics, chemicals, herbicides and insecticides. The use of antibiotics and chemicals for the treatment of disease is commonly required in intensive fish culture systems. In extensive and semi-intensive systems chemical are often used for the control of fish parasites and also in pond preparation for the removal of predators. GER for insecticides and herbicides are quoted at about 100MJ/kg (95-102MJ/kg). As these items are a relatively insignificant component of the total GER, the range of error in this figure is of little significance.

20 Packing and marketing.

Most of the case studies examine the production process up to the farm gate product. In some cases the production costs include packaging of the product for ex-farm sales. In the case of Salmon this requires ice and boxes. For mussels simple plastic mesh bags are used. The GER of these items is calculated from the weight and material conversion value, as specified. The GER for flake ice, purchased locally, is assumed at 0.94MJ/kg.

21 Site lease, stock insurance, legal and professional.

These items will involve some energy input in the form of the manpower and accommodation, but this will be negligible in comparison to other inputs and is therefore ignored here.

Insurance and maintenance of vehicles, equipment and buildings: Costs calculated as a percentage of capital costs as specified. Legal and professional services have been entered at a fixed rate financial cost and zero energy cost.

22 Maintenance

Energy requirement for the maintenance of capital facilities and vehicles are included as a percentage of the capital GER, 6% for vehicles (ref 8) and 2% for buildings and other facilities (own estimate, boats and cages requiring the greater part, shore facilities requiring a minimal amount). In the case of salmon production, the GER for these items comes to less than 0.1% of the operating GER. The accuracy of the figure chosen is therefore relatively unimportant.

Annex 4 Financial and energy analysis of intensive salmon production in sea water cages. Presentation of the model and assumptions.

A4.1 Introduction

Salmon farming represents one of the most advanced and important intensive marine aquaculture activities in the world. Production is dominated by three species; Coho, Chinook and Atlantic of which the last, (*Salmo salar*), is the most important in terms of present market share for farmed salmon. This case is based on data from the Scottish salmon farming industry (*S. Salar*), which represented 20 % of the world production for this species in 1991 (FAO 1993). Data were collected during visits to commercial farms, discussion with farmers and suppliers to the industry, and from the available literature.

Farmed salmon are produced in both land based tanks, with a pumped supply of sea water, and in floating net cages in sea water. The latter method accounts for about 98% of the total Scottish production, and will therefore form the basis for this analysis. The spreadsheet model for this case is presented in Table 1 below. This gives capital and operating requirements of a medium size cage unit, with a steady state production of 200t per annum.

The following notes provide background information on specific assumptions with reference to the spreadsheet model. The methodology and structure of the model is discussed in Annex 2. Details of the GER (Gross Energy Requirement) conversion values applied to inputs are given in Annex 3. For details of the production cycle of S. Salar, see Bjorndal (1990).

Notes

I Outline specifications (Table 1, page 1)

(For general comments, see text, Annex 2)

1. Production: An output of 200 tonnes per annum represents a medium size single site operation in Scotland.

2. Market price: There are considerable variations depending on the size and quality of the fish, the location of the farm and the time of the sale; In 1988/89 there was a marked reduction from the previous year. Very roughly, in 1987/88, prices for salmon were between £3.75/kg and £4.75/kg, while in the following year most of the sales were between £3.25 and £4.25/kg. The price of Grilse (and pre-salmon, harvested before the second winter at sea) is lower than the salmon price (Industry sources). In the base case model an average price of £3.5/kg and £4.5/kg is assumed for grilse and salmon respectively.

3. Production performance: These items are based on the average figures for the Scottish industry for the three years up to 1989 (DAFS, 1990).
Harvest weight (mean per fish) of 2.2kg and 3.5kg for grilse and salmon respectively
Survival over the production cycle of 1.5-2.5 years from stocking as smolts to harvest as grilse or salmon averaged about 70%. Grilse rate represents about 30% of total numbers stocked. Food conversion rate (FCR) of 1.8:1 is taken as an average for the industry for the period 1987-89.

4. Financial assumptions. These are discussed in Annex 2.

II Capital inputs (Table 1, page 2 & 3).

Details of the capital inputs are given for financial and energy analysis. Costs of items and quantities of component materials for each item are provided. Energy conversion values for component materials have been obtained from the literature, and a list of values and sources is provided in Annex 3, Table 1. Energy values used will be discussed only where the item is of particular significance to this case, or is not listed in Annex 3.

5. Cages: The model farm comprises two groups of six steel frame cages, each cage having a surface area of 15m by 15m. The net depth is 10m. Buoyancy is provided by the low density plastic with a high density plastic coating. Cage nets are of two mesh sizes, as specified. Spare nets (one per two cages) allow for cleaning periods. All cages have top nets, and both groups are surrounded by a large mesh predator nets. Two tarpaulins to enclose cages for sea-lice treatment have been included. The requirement for cage volume assumes grow-out to a final stock density of 15kg fish/m^3, from stocking as smolts. Therefore each cage group will produce a total of 200 tonnes over a two year cycle, with a partial harvest during the first year.

6. Moorings: Detailed specifications for mooring of fish cages, at an average Scottish fish farm site, were obtained form specialist suppliers. Here a combined figure for most component costs is given, but detailed quantities of component material are included.

7. Equipment: Figures for items of site equipment were obtained from specialist manufacturers. The grader is assumed to be a simple GRP table for hand grading of stock. Mechanical grading is not generally practised. Automatic feeders provided for all cages, and 3 feed bins are provided on each group of Six cages. A pump is required for grading and for operation of the net washer. Scales are required for sample weighing and post harvest weighing. Other miscellaneous items have been included in the financial data but are not accounted for in the energy budget, as these will be relatively insignificant.

8. Boats: includes a 12 tonne steel hulled landing craft type work-boat, with an 80 hp diesel inboard motor plus two One tonne steel work-boats. Three 25 hp outboard motors are required (Manufacturers specifications).

9. Shore facilities and buildings: Includes a concrete jetty (100m^3 concrete plus rock infill) and a building comprising of a feed store, packing shed and office, (including furnishings and services) as specified.

10. Vehicles: Includes a pick-up and forklift truck.

11. Transport of capital items to site. The financial analysis assumes that the delivery charge is included in the item cost. For energy analysis it is assumed a 500km round trip by road is required for the delivery of capital items (except buildings and concrete).

III Operating Inputs (Table 1, page 4)

12. Feed: An average price of £550 per tonne is assumed for the range of Salmon feeds required throughout the production cycle. The quantity of feed is calculated from the total output and the expected FCR (see note 3). In the investment appraisal a reduction in the assumed feed requirement is made for year 1, as stock consists of the first years input of smolts only. The GER applied to Salmon feeds is critical in the determination of the final GER of the output. This is discussed in Annex 3.

13. Stock: The number of smolts required is a function of output, losses, grilse rate and harvest weights. An average cost of £1.30 is assumed (omitted in year 10 for investment appraisal). The energy cost of smolts is based on a smolt production case study (not included here). This suggests that the GER of an average smolt (weight 50g) is 5.5 MJ.

14. Transport: This item refers to the transport of feed and stock to the site. A round trip of 500km is assumed for all deliveries. The cost of transport is normally included in the purchase price, therefore set at zero here. The GER of transport, based on weight and distance, is discussed in Annex 3. For smolt delivery, it is assume that one tonne of water is required per 2000fish (at 50g each gives a density of 100kg/m^3, giving and effective transport weight of about 0.5kg per fish)) Smolt delivery to more isolated sites is now carried out by well-boat, but any gain in this respect is likely to be offset by the additional costs of feed transport. Here all deliveries are assumed to be by road.

15. Pharmaceutical/ chemicals: Estimates of cost of this item varies considerably from site to site. A industry average of £50 per tonne was estimated for veterinary inputs and medical supplies. It is assumed that this cost is primarily associated with the purchase of antibiotics, which range from £30 to £100 per kg. In this model veterinary services are considered separately, and a medical supplies cost of £40 per tonne output is assumed, representing 1kg antibiotic per tonne.

16. Labour: This includes Six full time labourers, plus a manager and a part time secretary. It is assumed that the standard working year consists of 48 five day weeks, ie 240 days (ave 8 hours) for six staff. Weekend staffing consists of two workers. Each worker therefor must work an additional 35 days per year, giving a total of 275days per person-year. The manager is also assumed to work 275 days, and the part time office worker 120 full days equivalent.

17. Fuel and power: Fuel for operation of boats, pumps and site vehicles. The fuel usage will depend on the location. A total usage of 10000 litres petrol per year is based on each outboard motor boat using 10 l/day, plus an annual consumption of 2000l for the pick-up, plus several hundred litres for operation of the pump etc. The diesel boat and forklift are assumed to use 6000 litres per year. Power for land base assumes an annual usage of 2000KWh.

18. Office costs: includes stationary, phone postage. This item is assumed to incur a negligible energy cost and is therefore not included in the energy budget.

19. Ice and boxes: It is assumed that all fish harvested are packed whole in polystyrene boxes (0.3kg) at 25kg fish per box with an equal quantity of ice. The energy cost of a box is based on a GER of 144MJ/kg polystyrene. Flake ice, purchased locally, has an energy cost of 941MJ/t.

20. Site lease and stock insurance: This is a cost of production based on the total output of the site.

21. Insurance and maintenance of vehicles, equipment and buildings: Costs calculated as a percentage of capital costs as specified.

22. Veterinary, legal and professional services are set at a fixed rate. Interest on investment and operating capital as specified.

IV Outputs and revenues (Table 1, page 4 and 5).

23 The steady state output is 200 tonnes per year, consisting of 60t grilse(12-18 months from stocking) and 140t salmon (24-30 months from stocking). A build-up in output is required as a result of the above production cycles. (years 1, 2, 3 output 0t, 60t and 200t respectively. For investment appraisal, it is assumed that all fish stocked in year 9 will be harvested in year 10 at the grilse weight and price, giving a total output in year 10 of 288t. Due to these factors the average production over the ten years of operation is only 175t per year, although the output capacity is 200t. Market price is discussed in note 2.

Annex 4. Table1. FINANCIAL AND ENERGY ANALYSIS OF INTENSIVE SALMON PRODUCTION IN SEA CAGES
Page 1 of model

OUTLINE SPECIFICATIONS				
NOTES: 1	Annual production (tonnes)	200	175	Actual ave production due to build up in yr1 & 2.
2	Market price (per kg)	3.5	4.5	(Grilse/Salmon), including packing
3	Harvest wt (kg)	2.2	3.5	(Grilse/Salmon)
	Survival to harvest	0.7		
	Harvest number	27273	40000	(Grilse/Salmon)
	Stock number	96104		
	Grilse rate /Salmon	0.3	0.7	(Grilse/Salmon)
	FCR	1.8		
	Feed cost/tonne £ & MJ	550	40000	
	Transport km & GER/t km	500	4	MJ/t km
4	Discount Rate %	15		
	Interest (real) % or opportunity cost capital	8		Assumed interest on borrowed capital and opportunity cost of investors capital are equivalent.
	Tax rate %	40		
	Grant:capital %	0		
	Grant:working capital %	0		yrs 1 and 2
	Sensitivity multipliers			
	Capital inputs	1		Adjusts total costs, annual depretiation and energy values
	Operating inputs	1		Adjusts operating costs and energy values
	Labour (financial)	1	0	GER labour in base case
	Marketing (packing/ice)	1		One in the base case for GER calculations.

Annex 4 Table1 (Continued)
SUMMARY OF INPUT AND OUTPUT DATA
(Page 5 of model)

OUTPUT	STEADY STATE Total	Grilse	Salmon	TEN YEAR AVERAGE** Total
PRODUCTION (P, tonnes)	200	60	140	175
MARKET PRICE (p; £/kg)		3.5	4.5	
REVENUE Ra, £ total	840000	210000	630000	723800

INPUTS (sensitivity multipliers)*		FINANCIAL (£ Sterling) Steady state £	%	FINANCIAL (£ Sterling) Average ten years £	%	GER MJ Steady state MJ	%	GER MJ Average ten years MJ	%
(Capital	1								
(Operating	1								
CAPITAL depreciation, Ca;m(a)		50972	8.3	50972	8.8	1149300	6.3	1149300	6.6
OPERATING (total) Va:l(v)		493566	80.8	466266	80.2	16982131	93.7	16170988	93.4
INTEREST (cap & op) Ia:		66268	10.8	64084	11.0				
TOTAL costs Ta:		610806		581322		18131431		17320288	
Cost per kg whole fish		3.05		3.33	100%	90.66	MJ/kg	99.09	100%
Cost per kg meat***	70.0%			4.75		129.51		141.55	
Cost per kg protein	14.4%			23.09		629.56		688.10	

INVESTMENT APPRAISAL		
Discounted @	15%	over ten years
NPV £	48237	
IRR %	17%	

Sensitivity analysis factors	% Base Case for 10 year average	
Unit prodn costs	3.33	100%
Unit prodn GER	99.09	100%

FISH FEEDS: Contribution of feed to costs

	financial £/t	GER MJ/t
	550	40000
Contribution to cost	% COSTS	% GER
Operating	40%	85
Total	32%	79

Labour requirements	
Operating labour, days/yr.	1990
Days /t, steady state	9.95
kg/ labour day	101

* sensitivity multipliers for financial and energy inputs
** Production cost and GER 10yr ave allows for reduced inputs in build-up period using the average production over the Ten years of operation
*** Values for % meat and % protein from TDRI (1981)

Annex 4. Table1 (Continued) FINANCIAL AND ENERGY ANALYSIS: SALMON IN SEA CAGES (page 2 of model)

									SPECIFIC GER OF COMPONENT MATERIALS (m'(k))														
						Material identifier		(k) =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
									VEHICLES MOTORS	STEEL manufact.	Aluminium	HDP PVC	P-ethylene	LDP P-styrene	P-propylene	Nylon	GRP	BUILDING	CONCRETE	EARTH MOVING	EARTH MOVING	TIMBER BAMBOO	OTHERS
					Units				kg	kg	kg	kg	kg	kg	kg	kg	kg	per sqr m	/m^3	/m^3	/hour	kg	
					GER MJ/unit (m'k)				85	85	320	130	105	144	125	175	80	1200	2760	23	500	9	0
					sensitivity multipliers				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CAPITAL INPUTS			Financial costs C (Sterling) Energy, GER, : m (MJ)						QUANTITY OF COMPONENT MATERIALS m"(ijk) (kg)														
Notes	ITEM (i) Class	NO. ITEMS (n)	COMPONENTS (ij) per item	SPECIFICATIONS per item	COST C(ij) per item	COST C(ij)n Total	LIFE (T(ij)) years	ANNUAL DEPRETN C(ij)n/T straight line	VEHICLES MOTORS	STEEL:	ALUMINIUM	PLASTICS HDP PVC	P-ethylene	LDP P-styrene	P-propylene	Nylon	GRP	BUILDING per sqr m	CONCRETE m^3	EARTH MOVING m^3	EARTH MOVING /hour	TIMBER BAMBOO kg	OTHER
5	CAGE	12			9000	108000	10	10800															
		12	Frame	15m*15m steel		0	10	0		4250						0	0	0					
		12	Floatation			0	10	0					270	540									
		10	Nets:cage	10m deep, 18mm me	2000	20000	3	6667								124							
		8	nylon	10m deep,12.7mm m	2300	18400	3	6133								152							
		2	Tarp. for sea lice treatment		400	800	5	160					100			50							
		2 (	Predator nets	perimiter	326	652	3	217					10										
		12 (	4" square	top nets	120	1440	3	480					10										
						0	10	0															
6	MOORING	2	Anchors	Samson 8*200kg		0	10	0							0								
		2		Samson 8*100kg	5120	10240	10	1024		2400													
		2	Other	Chain		0	10	0		5440													
			components	Rope		0	5	0							487								
				Buoys		0	5	0					56										
				Labour		0	5	0															
		2		Total others	10176	20352	5	4070															
7	GRADER	1	Fiberglass tray		300	300	5	60		0							15						
7	FEEDERS	12		Hoppers 100Lcap	100	1200	5	240					6										
		1		Electrics	400	400	5	80															
		6		Feed bins	200	1200	5	240					15										
7	SCALES	1	Scales		1000	1000	10	100		60													
7	MISC	1	Misc (Hand nets, clothing, etc)		4000	4000	2	2000		20						10							
						0	1	0															
7	PUMP	1	Pump		2000	2000	5	400	40														
7	NET WASHER	1	Net washer (steel & GRP) 10m3		12000	12000	5	2400		600							600						
						0	10	0															
8	BOATS	1	Boat	Barge/inboard	45000	45000	10	4500		12000													
		2		Dory(steel)	2000	4000	5	800		1000													
		3		Outboard 25hp	1600	4800	2	2400	50														
	SHORE FACILITIES					0	10	0															
9	JETTY	1	100 m^3 Concrete		5000	5000	10	500											100				
						0	10	0															
9	BUILDINGS	1	Store	200m^2)		0	20	0															
		1	Packing shed	100m^2	50000	50000	20	2500										350					
		1	Office/staff rm	50m^2)		0	20	0															
		1	Furnishings etc	)		0	20	0															
10	VEHICLES	1	Pickup, car		12000	12000	3	4000	1200														
		1	Forklift (second hand)		12000	12000	10	1200	3000														
11	TRANSPORT		Capital items to site		0	0	0																
	CAPITAL INPUTS		TOTAL COSTS C(I)			334784																	
	Financial summary		Annual capital depreciation; C(a)					50972															
			Interest on capital (@ 100% borrowing)			26783																	
	Energy input summary																						
			Capital GER per year MJ: m(a) (AR83)			1149300																	
			Capital GER per tonne output MJ (AR84)			5747																	

Annex 4 Table1 (Continued) FINANCIAL AND ENERGY ANALYSIS: SALMON
Page 3 of model

TOTAL GER OF EACH COMPONENT MATERIAL INPUT (kg) [m(ijk)n)=m'(ijk)m'(ijk)n]

VEHICLES MOTORS	STEEL	ALUMINIUM	PLASTICS HDP PVC	P-ethylene	LDP P-styrene	P-propylene	Nylon	GRP	BUILDING per sqr m	CONCRETE m^3	EARTH MOVING m^3	EARTH MOVING /hour	TIMBER BAMBOO kg	OTHER	TOTAL GER component ave annual (m(i))n= Sum m(ijk)n]	GER/YR component ave annual [m(i)n/T]	Transport Total wt/life of item
															0	0	0
0	4335000	0	0	0	0	0	0	0	0	0	0	0	0	0	4335000	433500	5100
0	0	0	0	340200	933120	0	0	0	0	0	0	0	0	0	1273320	127332	972
0	0	0	0	0	0	0	217000	0	0	0	0	0	0	0	217000	72333	413
0	0	0	0	0	0	0	212800	0	0	0	0	0	0	0	212800	70933	405
0	0	0	0	21000	0	0	17500	0	0	0	0	0	0	0	38500	7700	60
0	0	0	0	2100	0	0	0	0	0	0	0	0	0	0	2100	700	7
0	0	0	0	12600	0	0	0	0	0	0	0	0	0	0	12600	4200	40
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	408000	0	0	0	0	0	0	0	0	0	0	0	0	0	408000	40800	480
0	924800	0	0	0	0	0	0	0	0	0	0	0	0	0	924800	92480	1068
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1200	0	0	0	0	0	0	1200	240	3
0	0	0	0	7560	0	0	0	0	0	0	0	0	0	0	7560	1512	14
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	9450	0	0	0	0	0	0	0	0	0	0	9450	1890	18
0	5100	0	0	0	0	0	0	0	0	0	0	0	0	0	5100	510	6
0	1700	0	0	0	0	0	1750	0	0	0	0	0	0	0	3450	1725	15
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3400	680	8
0	51000	0	0	0	0	0	0	48000	0	0	0	0	0	0	99000	19800	240
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1020000	0	0	0	0	0	0	0	0	0	0	0	0	0	1020000	102000	1200
0	170000	0	0	0	0	0	0	0	0	0	0	0	0	0	170000	34000	400
12750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12750	6375	75
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	276000	0	0	0	0	276000	27600	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	420000	0	0	0	0	0	420000	21000	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102000	34000	400
255000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	255000	25500	300
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		22489	

Capital GER per year (MJ) [m(a)=Sum (m(i)n/T)] 1149300
Capital GER per tonne output (MJ) [m(a)/P] 5747

Transport GER per MJ/t km	—	4
: Distance km	-------	500
: Annual weight t	-------	11.24
Total annual GER transport =		22489

CALCULATION OF ADDITIONAL CAPITAL EXPENDITURE DURING PROJECT LIFE

Year	1	2	**	3	**	4	**	**	5	**	6	**	**	**	7	**	8	**	**	**	9	**
Replace item if life =	1	2	1	3	1	4	2	1	5	1	6	3	2	1	7	1	8	4	2	1	9	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	20000	0	0	0	0	0	0	0	20000	0	0	0	0	0	0	0	0	0	0
	0	0	0	18400	0	0	0	0	0	0	0	18400	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	800	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	652	0	0	0	0	0	0	0	652	0	0	0	0	0	0	0	0	0	0
	0	0	0	1440	0	0	0	0	0	0	0	1440	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	20352	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	1200	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	400	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	1200	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	4000	0	0	0	0	4000	0	0	0	0	0	4000	0	0	0	0	4000	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	2000	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	12000	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	4000	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	4800	0	0	0	0	4800	0	0	0	0	0	4800	0	0	0	0	4800	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	12000	0	0	0	0	0	0	0	12000	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	8800	0	52492	0	0	8800	0	42252	0	0	52492	8800	0	0	0	0	8800	0	0	0	0

Additional capital inputs

Year	1	2	3	4	5	6	7	8	9
Capital £*1000 =	0	8.8	52.49	8.8	42.252	61.29	0	8.8	0

Annex 4. Table1 (Continued) OPERATING INPUTS FINANCIAL AND ENERGY ANALYSIS: SALMON (Page 4 of model)

FINANCIAL BUDGET				Financial costs: V (£sterling)				ENERGY BUDGET		Energy, GER,: f(MJ)		
ITEM (i)	Quantity of item f*(i)	Units	Specifications	Cost/unit V(i)	Total cost/item V(i)f*(i)	% Total Cost		Energy cost MJ/Unit f'(i)		Energy cost MJ/item f=f'(i)f*(i)	% Total Energy	Sensitivity multipliers for GER
					0					0		
12 FEED	360	tonnes, t	30%yr1,70%yr10	550	198000	40.12		40000		14400000	84.80	1
13 STOCK	96104	smolts @ 50g	none yr 10	1.3	124935	25.31		5 5		528571	3.11	1
					0			40	0	0	0.00	1
14 TRANSPORT	408	t @ 500km	Feed and Smolts	0	0	0.00		2000	4MJ/(t km)	816104	4.81	1
15 PHARMACEUT	200	t stock	Antib, Nuvan	40	8000	1.62		100		20000	0.12	1
					0				either = 0	0	0.00	1
16 LABOUR	6	* persons (270 days), av salery		10000	60000	12.16	1	0	or13MJ/dy	0	0.00	1
16 MANAGER	1	* person (270 days)		15000	15000	3.04	1	0	"	0	0.00	1
16 SECRETARY	1	* person, prt time (100 days)		3500	3500	0.71	1	0	"	0	0.00	1
		* days per unit			0			40	(or 40MJ/£)	0.00	0.00	0
17 FUEL	10000	litres petrol	boat/pump etc	0.45	4500	0.91		40		400000	2.36	1
	6000	litres Deisel	barge/forklift	0.35	2100	0.43		40		240000	1.41	1
17 POWER	4000	KWhrs	for land base	0.05	200	0.04		9		36000	0.21	1
					0					0	0.00	1
18 OFFICE COSTS	1	lump sum	Statnary, phone	1500	1500	0.30		0		0	0.00	1
					0					0	0.00	1
										0	0.00	1
19 ICE	200	tonnes @ 1:1		20	4000	0.81		941		188200	1.11	1
19 BOXES	8000	number @ 25kg fish per box		2.5	20000	4.05		43 2	.3kgpolystyı	345600	2.04	1
				100	0					0	0.00	1
INSURANCE, MAINTENANCE, LEGAL AND PROFESSIONAL					0					0	0.00	1
20 SITE LEASE	200	PER TONNE	Crown Estates	50	10000	2.03		0		0	0.00	1
20 INSURANCE stk	200	tonne output	cost per tonne	110	22000	4.46		0		0	0.00	1
					0				Capital E	0	0.00	1
21 INSURANCE cap	310784	* capital cost of facilities		0.02	6216	1.26		0	9452030	0	0.00	1
21 MAINTENANCE	310784	* and buildings		0.02	6216	1.26		0 02	9452030	6216	0.04	1
					0	0.00		0		0	0.00	1
21 VEHICLES	24000	* capital	Ins, maint	0.10	2400	0.49		0 06	357000	1440	0.01	1
					0					0	0.00	1
22 VETERINARY	1	fixed rate		2500	2500	0.51				0	0.00	1
22 LEGAL&PROF	1	fixed rate		2500	2500	0.51		0		0	0.00	1
		TOTAL OPERATING COSTS, Va,			493566	100			Energy(MJ)	16982131	100	
		Grants for working capital years 1 and 2.			0				[sum(f'(i)n)]			
22 COST OF CAPITAL		(for unit production cost calculations)										
INTEREST on £	334784	investment capital @ % rate		0.08	26783							
INTEREST on £	493566	working capital @ % rate		0.08	39485							

			TOTAL COST OF CAPITAL:		66268							

OUTPUT AND REVENUES	steady state output tonnes		£	Year, y	1	2	3	4 to 9	10	Total	Average /yr
23 Annual production: P(t)	200				0	60	200	1200	288	1748	174.8
Grilse: Market price p1	3.5	60	210000		0	210000	210000	1260000	210000		
Salmon: Market price p2	4.5	140	630000	0	0		630000	3780000	630000		0
Extra pre salmon yr ten	3.5	88							308000		
REVENUE, R	Ra =		840000	Ry =	0	210000	840000	5040000	1148000	7238000	723800

Annex 5 Financial and energy analysis of intensive finfish culture in sea cages, Indonesia Presentation of model and assumptions.

A5.1 Introduction

There is a growing interest in SE Asia in the intensive culture of high value fish species, either for luxury local market, or for export to major consuming regions such as Hong Kong, Japan and Singapore. This case examines a marine cage based operation in Indonesia. The data was obtained from FAO/UNDP/PPTBL (1986) project INS/81/008 " package technology for culture of marine finfish in floating net cage". The object was to develop practical procedures for the culture of Sea bass (*Lates calcarifer*) and Groupers (*Epinephelus sp.*). It is not clear from the available documentation whether this technology has been successfully developed on a commercial scale.

A5.2 Notes

These notes provide information specific to this case, presented in Table 1 following. More general details of the model and assumptions are presented in Annex 2 and 3.

I Outline specifications:

1 Production: This is a small scale intensive culture operation with a total annual output of about 3.6 tonnes from two harvests: is was proposed as a family scale operation which might be operated by fishing families as a source of diversification.

2 Stock and harvest numbers, and feed assumptions are discussed below.

3 General financial assumptions are discussed in Annex 3

II Capital inputs.

4. Cages: A raft of four cages, 3m square (27m^3), constructed as follows: The frame, which supports cage nets and provides a walkway, is constructed from bamboo poles and wooden planks. Floatation is provided by old oil drums, plastic industrial fluid containers or polystyrene. In this case it is assumed that oil drums are used. Steel wire is used to hold the structure together. The bamboo will be replaced annually, but the wooden walkways will last for Four years. Oil drums are assumed to last for two years.

Nets are made from polyethylene (nylon nets suffer from sun damage in the tropics) and are expected to last for two years.

5. Moorings: consist of four 25kg steel anchors plus 100m of 20mm Polypropylene or nylon rope. The design of mooring system will depend on the shelter of the site. Cheeper systems can be constructed using concrete blocks or wooden stakes, but this is only suitable for very sheltered sites. It is assumed that in this case the steel anchors will have a life of Ten years, while the ropes will be replaced every Two years

6 Other items: The "Package Technology" does not include a boat, hand nets, scales, feed bins etc. in the details of capital costing. However, discussion of site management and record keeping includes the maintenance of craft, fuel costs, transport costs. Accessory facilities mentioned include sea transport, fish holding equipment (for marketing of live fish), pumps etc. In addition to a maintenance allowance of 10% of capital costs, the annual operating costs include miscellaneous costs of Rp 700,000.

It is assumed that the site with depth sufficient for these cages (say minimum of 5m depth) will not be close enough to the shore to allow a walkway, and that a boat will be required. The Package Technology suggests that such a small scale operation could be a part time activity carried out by fishermen, and that a boat,and much of the other miscellaneous equipment required is already available (the proposed package allocates operating costs for these items, but not capital). For the purpose of the model we will assume that the fish culture activity incurs no extra capital expenditure associated with boats or other unspecified equipment.

7 Transport of capital items. It is assumed that all transport costs are included in the figures given. For the energy analysis, the GER of transport is calculated assuming an average transport distance of 100km.

II Operating inputs

8. Feed: The project suggests a range of alternative sources of feeds including fresh trash fish, a semi-moist diet and a dry fish meal based feed. In the operational specifications, data on costs and expected performance is given for the trash fish diet only. This is composed of low value fresh fish, molluscs and crustacean and costs about Rp250/kg. A FCR of 5:1 is assumed. The GER will depend on the type (pelagic or demersal) and scale (ranging from local to distant water) of fishery (see Annex 3). Here a value of 20MJ/kg is assumed in the base case.

9 Stock: numbers required depend on the total output, the mean harvest weight and the survival rate. Data provided suggests a survival of 90% from stocking at a mean weight of 120g. Two crops totalling 3.6 tonnes, with a mean harvest weight of 840g requires an initial stock of about 4800 fish.

Stock for this farming operation are assumed to come from wild caught fry, purchased from commercial seed collectors. They must then be packed, transported to the farm site. Wild caught fry will have to be reared in nursery system before stocking the ongrowing facility. These fish are initially fed a fresh fish diet, and sometimes weaned onto moist or dried diets. Early rearing uses nursery cages, but no data for the systems required or the costs involved was provided in the technical manual. The cost quoted for these fingerlings is Rp200 each. An estimate of the potential energy cost of fingerlings assumes hatchery reared stocks, using the figure calculated for Salmon smolts as a guide.GER for fingerlings is calculated as follows:

> For a 50g Salmon smolt, the estimated GER is .....6 MJ each
> Assume a similar GER for a 50g fish in this case, For required 120g fish to stock this system, additional growth required is 70g. At FCR 3:1, feed required is 210g, at above GER of 20 MJ/kg, = additional 4.2MJ per fish.
> Therefore estimated total GER for fingerlings is approximately 10MJ each.

10 Labour. This case assumes one full time employee costing 60,000 per month (the technology manual suggests that this could be provided as family labour). It is not clear if the sums allocated covers all labour requirements: security needs may require 24 hour site guarding. The manual does not specify how much additional labour is expected to be contributed by the operator. For the purposes of this analysis, an allowance for a management input of 60000 per month is made. This is assumed to be equal to a total of 12 days per month.

11 Miscellaneous. The inclusion of Rp700,000 in the operating costs of the package technology is discussed in Note 6 above. For the financial analysis this is assumed to cover fuel transport, and other potential costs such as chemicals and pharmaceuticals. Costs are therefore set at zero under these specific items in the case study. For energy analysis, estimates of potential fuel usage is included in the GER calculation. Other items are not considered, as they were found to be relatively insignificant in preliminary analysis.

12 Maintenance: requirements have been estimated at 10% of capital costs (figure given in technical paper). This does not account for the potential maintenance cost of items not listed under the capital inputs (see Note 6.), although this assumption is tested by varying total capital costs in the sensitivity analysis. The energy cost of maintenance is taken as a notional 2% of capital energy costs, as replacement of materials has been allowed for in the capital specifications (ie life of inputs).

13. Legal and professional Not included.

14. Output and Revenues: It is assumed that in the first full year the output will be 50% of the proposed yield of 3.6 tonnes/ year. This allows for unexpected production and management problems while the operators gain experience. Fish are sold live, with an ex-farm price of Rp3500/kg.

Annex 5. Table 1 FINANCIAL AND ENERGY ANALYSIS OF FINFISH CULTURE IN SEA CAGES (INDONESIA)
Source: FAO/UNDP/PPTBL 1986. Package technology for culture of marine finfish in floating net cage.

OUTLINE SPECIFICATIONS AND KEY INPUT VARIABLES				
NOTE				
1	Production per crop (kg)	1800		
	Crops per year	2		
	Annual production (kg)	3600	3420	Average annual production over 10 years
	Market price (per kg)	3500		(no output in year 1)
2	Harvest wt (g)	840		
	Survival to harvest	0.9		
	Harvest number	4286		
	Stock number	4762		
	Stock weight Mean, g	120		
	FCR	5.5		
	Feed cost /kg, financial	250	20	GER feed, MJ/kg
			0	GER labour
3	Discount Rate	15		
	Interest (real) %	8		Assumed interest on borrowed capital and opportunity cost
	or opportunity cost capital			of investors capital are equivalent.
	Tax rate %	40		
	Grant:capital %	0		
	Grant:working capital %	0		yrs 1 and 2
	Sensitivity multipliers			
	Capital inputs	1		Adjusts total costs, annual depreciation and energy values
	Operating inputs	1		Adjusts operating costs and energy inputs
	Packing	1		

Annex 5 Table 1 (continued) SUMMARY OF INPUT AND OUTPUT DATA (page 5 of model)

OUTPUT	STEADY STATE Total		TEN YEAR AVERAGE** Total					
PRODUCTION (KG)	3600		3420					
MARKET PRICE (Rp/kg)	3500							
REVENUE Rp (*1000) total	12600		11970					
INPUTS	FINANCIAL (Rs*1000) Steady state		FINANCIAL (Rs*1000) Average ten years		GER MJ Steady state		GER MJ Average ten years	
(sensitivity multipliers)*	Rs	%	Rs	%	MJ	%	MJ	%
(Capital 1								
(Operating 1								
CAPITAL depreciation, Ca;m(a)	548	4.9	548	4.9	11701	2.4	11701	2.4
OPERATING (total) Va:f(v)	10278	92.4	10278	92.4	481831	97.6	481831	97.6
INTEREST (cap & op) Ia:	297	2.7	297	2.7				
TOTAL costs Ta:	11122		11122		493532		493532	
Cost per kg whole fish***	3090	Rs	3252	100% Rs	137.09	MJ/kg	144.31	100%
Cost per kg meat 55.0%			5913				262.38	MJ/kg
Cost per kg protein 11.0%			29565				1311.89	MJ/kg

INVESTMENT APPRAISAL		Sensitivity analysis factors	% Base Case for 10 year average
Discounted @	15.00		
NPV Rs *1000	1197	Unit production costs	100.0%
IRR %	25%	Unit production GER	100.0%

FISH FEEDS: Contribution to financial and energy costs

	COST Rs/t	GER MJ/t
	250000	20000
Contribution to cost	% COSTS	% GER
Operating	48%	80%
Total	44%	78%

Labour requirements (steady state)

Operating labour, days/yr.	306
Days labour /t	85
kg/day	12

* sensitivity multipliers for financial and energy inputs
** Production cost and GER 10yr ave allows for reduced inputs in build-up period using the average production over the Ten years of operation
*** Meat and protein content estimated from TDRI (1981)

Annex 5. Table 1 (continued) MATERIAL AND FINANCIAL SPECIFICATIONS

CAPITAL INPUTS

Note:	ITEM (i) Class	NO. ITEMS (n)	COMPONENTS (ij) per item	SPECIFICATIONS per item	COST C(ij) per item	COST C(ij)n Total	LIFE (T(ij)) years	ANNUAL DEPRETN C(ij)n/T (STR LINE
4	RAFT OF FOUR CAGES					0	2	0
		16	Bamboo poles	20cm dia * 8.0m	3000	48000	1	48000
			(frame)			0	2	0
						0	2	0
		20	Wood planks		2500	50000	4	12500
						0	2	0
		15	Floats	44gal oil drums	10000	150000	2	75000
						0	2	0
		1	Steel wire	18kg for bamboo	15000	15000	1	15000
				joints		0	2	0
		6	Nets	Polyeth,5kg/net	112500	675000	2	337500
						0	2	0
5	MOORINGS	4	Anchors	Steel, 25kg	25000	100000	10	10000
						0	2	0
		1	Ropes	Nylon, (25kg)	100000	100000	2	50000
				100m @ 20mm dia		0	2	0
			16		0	0	2	0
6	Other inputs		not included in specifications			0	2	0
			Boat			0	2	0
			Outboard motor			0	2	0
			hand nets, buckets, scales etc			0	2	0
						0	2	0
						0	2	0
7	TRANSPORT		Capital items to site		0	0	2	
	CAPITAL INPUTS		TOTAL COSTS			1138000		
	Financial summary		Annual depretiation on capital items					548000
			Interest on capital (@ 100% borrowing)			91040		
	Energy input summary							
			Capital GER per year MJ (AR..			11701		
			Capital GER per smolt producedMJ (AR..			3.25		

OPERATING INPUTS — FINANCIAL BUDGET

	ITEM (i)	Quantity of item f*(i)		Units	Specifications	Cost/unit V(i)	Total cost/item V(i)f*(i)	% Total Cost
							0	0.00
8	FEED	19.29		tonnes trash fish		250000	4821429	46.91
9	STOCK	4762		fingerling @ g	120	200	952381	9.27
						0	0	0.00
						0	0	0.00
10	LABOUR	12	25	man month per unit(25 days)		60000	720000	7.01
	MANAGER	6	1	" " " " " "		60000	360000	3.50
							0	0.00
11	MISCELLANEOUS	1		lump sum		700000	700000	6.81
						0	0	0.00
	ICE	3.6	1	tonnes at 1:1		100000	360000	3.50
	BOXES					0	0	0.00
11	TRANSPORT						0	0.00
11	PHARMACEUTICALS					0	0	0.00
							0	0.00
11	FUEL	900		litres petrol	outboard	2500	2250000	21.89
				@ 2.5l/day	feed transport		0	0.00
							0	0.00
	INSURANCE, MAINTENANCE, LEGAL AND PROFESSIONAL						0	0.00
						0	0	0.00
12	MAINTENANCE	1138000		Capital facilities at rate		0.10	113800	1.11
							0	0.00
13	LEGAL&PROFNAL	1		not included		0	0	0.00
				TOTAL OPERATING COSTS		Rp Indonesian	10277610	100
				Grants for working capital years 1 and 2.			0	
22	COST OF CAPITAL			(for unit production cost calculations)				
	INTEREST on Rs	1138000		investment capital	@ % rate	0.08	91040	
	INTEREST on Rs	10277610	0.3	working capital	@ % rate	0.08	205552	
		0.25		(*0.5/no.cycles)			--------	
					TOTAL COST OF CAPITAL:		296592	

			steady state output			from
23	OUTPUT AND REVENUES		Years	1	2	3
	ANNUAL PRODUCTION (kg)	3600		2700	2700	3600
	Market price	3500		3500	3500	3500
	REVENUE Rs	12600000		9450000	9450000	12600000

Annex 6. Financial and Energy analysis of Semi-intensive pond culture of Tilapia in rural Africa. Presentatation of model and assumptions.

A6.1 Introduction.

This model is based on data collected during a visit to government and smallholder fish farming operations in Southern Malawi, and the performance of similar systems elsewhere (Beveridge & Stewart 1986). A description of these systems, and the constraints to the application of quantitative methods of analysis are discussed in more detail in Chapter 7. This model is derived from those presented in Chapter 7, although some of the production and cost assumptions vary here.
below. Financial data represents 1986 values.

A6.2 Notes

These notes provide information specific to this case. A summary of assumptions, and the output of the model, are presented in Table 1 following these notes. More general details of the model and energy valuations are presented in Annex 2 and 3 respectively

I Outline specifications.

1 Productivity of the system. It is assumed that an annual yield of 1.0 tonne /ha/yr will be achieved from one harvest. This relatively low yield reflects the limited input resources and the relatively low ambient temperatures in the region. A total pond area of $500m^2$ is assumed, including a small brood stock pond ($100m^2$). The ongrowing pond is stocked with approximately 1 fish/m^2, with 70% survival to a mean harvest weight of 180g. In practice, a large size variation can be expected, and unless some process of selection for mono-sex production is occurs, problems of uncontrolled reproduction can limit growth. It is also unusual for the weight of the fish to be taken as a measure of output from these systems. Farmers normally refer to the size of the fish relative to their hand/forearm. This study will not be involved with the problems of reproduction, and assumes output to be quantified in weight. Details of feed and manuring rates are discussed in notes 7, 8 and 10.

2 Assumptions relating to market price, input and output costs, and opportunity cost of land are discussed in the main text Chapter 7.

II Capital inputs

4. Pond construction. This is , potentially, the main capital "cost " for the smallholder fish farmer. However, interviews with smallholder fish farmers and field studies carried out by other workers (Msiska and Nongwa, 1985) indicate that pond construction usually involves a large proportion of family labour, with varying levels of hired labour. Payments for hired labour were often made in kind rather than cash. One farmer had swapped a pig and some beans for assistance with pond construction. The actual cash costs incurred in existing pond systems ranged between 0 and 17t/m^2 pond surface (average 2.5t/m^2).

For the purpose of the study labour for pond construction is valued at MK0.25/m^2 (although family labour will not represent a cash cost, and may not represent an opportunity cost, if constructed in the dry season). This is derived as follows: Labour is assumed to be valued at the minimum agricultural wage of Mk0.85/day. For each square meter of pond area, 0.3m^3 of soil are moved (Hepher and Pruginin, 1981), and one man day (largely a male activity) is required per cubic meter (conservative estimate).

Drainage systems were not included in most of these small scale ponds, although some had a simple pipe drain built into the bank. Inflow systems varied in complexity, but were principally simple supply channels. For the purposes of the economic model an allowance of MK5.0 has been made for water systems. Energy requirements for pond construction relate totally to the labour used.

5. Equipment. Farmers interviewed did not buy any extra equipment for the construction or operation of their fish ponds, although several had borrowed a wheel barrow. The model fish farm costings assume that the farmer will barter for or borrow a wheel barrow, and a notional cost of equipment of MK 5.00 is used. There will also be some energy cost attributable to the tools which are required for construction. However, as these will be used mainly for other agricultural activities, the relative energy cost to the fish farming operation will be almost negligible. A minimal energy cost for tools is applied to this model.

III Operating inputs.

6. **Stock.** Fry are stocked at a rate of $1/m^2$. It is assumed that initially these can be obtained from the fisheries department, but later the farmers would produce fry from their own ponds. FD staff suggested that these would initially be provided free, with a charge applied only if further stocks were required. For this case, it is assumed that the cost of fry is included as a start-up cost, at a rate of MK0.01 per fish, with no operating cost.

Feeds and Fertilisers.

7. **Feeds**. The principal supplementary fish feed available to the smallholder is madea (maize bran - 25% of maize after milling) although other agricultural by-products and household scraps are used. Madea is reported to be readily available, cheap and has limited other uses. In practice it is not possible to determine a food conversion rate for madea as the final productivity is a result of all the inputs which directly or indirectly influence the feed availability for the fish. However, it is possible to make estimates of the output which can be achieved for a given level of the various inputs, deriving a notional, although not strictly accurate, FCR value for Madea inputs. Accurate data on inputs and yields from smallholder units is scarce. A FCR for madea of 3.4 : 1 was recorded for a heavily manured pond, while others local examples were between 5:1 and 6 : 1 (Msiska and Nongwa, 1985 quoted in Beveridge and Stewart, 1986). Landell Mills (1983) suggested a value of 4 : 1 for a well manured pond. Due to problems of availability of manure, and moderate manuring rates likely to be achieved (see below) a FCR of 5 : 1 has been used in this model.

For the purposes of the financial model, all madea used, whether available on the holding, bought by barter or with cash, is given a cash value of MK0.05 per kg (Grain and Milling Co., Blantyre)

The problems associated with attributing GER values to agricultural byproducts is discussed in the main text, and Annex 3, notes 12 -14. In the base case, a GER of 4.2 MJ/kg is assumed for maize bran.

8. Manure. A moderate manuring rate of 1.5 tonnes/ha yr is assumed. This is assumed to be mainly poultry manure as this is the most common livestock. The manure produced is also of high quality. In practice any manure or additional composted vegetable matter would contribute to productivity. If it is assumed that each chicken produces about 10kg dry manure per year (Landell Mills, 1983, suggests 12kg yr-1, Msiska and Nongwa suggest 8kg yr-1) then 7 -8 birds would be required for a 500m2 pond (75kg manure per year). This corresponds to the recorded average number of birds kept on holdings (ICRA, 1985). On most smallholder fish farms visited, birds were held in coops allowing the manure to be collected for pond fertilisation. As this manure might otherwise have been used on vegetable plots, for the purpose of the economic model, it has been given a notional value of MK0.03kg-1. No energy value has been attributed to animal manures or other inputs of organic matter (discussed in main text) and Annex 3).

9. Labour. For the financial analysis, the labour input was not included in costs, the output of the model representing the marginal returns to land and labour in comparison to that for the displaced crop. The basis for the estimation of the incremental benefits of the fish culture activity was that farmers indicated that the labour involved in fish culture was less than that required in the cultivation of other crops. It was therefore assumed in the model that the same labour would be required for crop and fish culture activities for a given production area.

10. Outputs and Revenues market price and yield assumptions are discussed above. It is assumed that the harvest in year 1 will be 50% of the steady state output.

Annex 6 Table 1 FINANCIAL AND ENERGY ANALYSIS OF SEMI-INTENSIVE POND CULTURE OF TILAPIA (AFRICA)
Source: Project proposal for the development of smallholder fish farming in Malawi

OUTLINE SPECIFICATIONS AND KEY INPUT VARIABLES

1	Production /crop (kg/ha)	1300	
	Crops per year	1	
	Pond area, m2	400	100 (production and breeding ponds)
	Annual production (kg)	58 5	(marketable yield from latter 50%)
	Harvest wt (g)	180	
	Survival to harvest	0 75	
	Harvest number	325	
	Stock number	433	
	Stock weight Mean, g	2 5	
	FCR (notional for madea)	5 5	
	Manuring rate kg/ha/y	1500	
	Manure cost (MK/kg)	0 03	0 fry cost
2	Market price (MK / kg)	1	
	Feed cost MK/kg & MJ/kg	0 05	4 GER feed, MJ/kg
	Value of displaced crop	300	MK Returns to labour per ha
	GER labour	0	
	Discount Rate	15	na
	Interest (real) % or opportunity cost capital	0	Assumed interest on borrowed capital and opportunity cost of investors capital are equivalent
	Tax rate %	0	
	Grant:capital %	0	
	Grant:working capital %	0	yrs 1 and 2
	Sensitivity multipliers		
	Capital inputs	1	Adjusts total costs, annual depretiation and energy values
	Operating inputs	1	Adjusts operating costs and energy inputs

Annex 6 Table 1 (cont) SUMMARY OF INPUT AND OUTPUT DATA

OUTPUT		STEADY STATE (ann		TEN YEAR AVERAGE					
		Total		Total					
PRODUCTION (KG)		58 5		58 5					
MARKET PRICE (MK/kg)		1							
REVENUE MK total		58 5		58 5					
INPUTS		FINANCIAL (MK)		FINANCIAL (MK)		GER MJ		GER MJ	
(sensitivity multipliers)*		Steady state		Average ten years		Steady state		Average ten years	
(Capital	1	MK	%	MK	%	MJ	%	MJ	%
(Operating	1								
CAPITAL depreciation, Ca;m(a)		11	33 0	11	33 0	43	3 0	43	3 0
OPERATING (total) Va:f(v)		22	67 0	22	67 0	1351	97 0	1351	97 0
INTEREST (cap & op) Ia:		0	0 0	0	0 0				
TOTAL costs Ta:		33		33		1394		1394	
Cost per kg whole	100 0%	0 57		0 57	100%	23 83	MJ/kg	23 83	100%
Cost per kg meat**	60 0%			0 95				39 71	MJ/kg
Cost per kg protein**	12 0%			4 75				198 55	MJ/kg

NET RETURNS TO LABOUR MK		Sensitivity analysis factors	
Total annual	25		% Base Case
Per day	2 52		for 10 year average
Value of lost crop	12		
Incremental returns to labour	13	Unit production costs	100%
Incremental returnsper day	1 32	Unit production GER	100 0%

FISH FEEDS: Contribution to financial and energy costs			Labour requirements (steady state)	
	FEED COST MK/t	FEED GER MJ/t	Operating labour, days/yr	10
	V(i)	f(i)	Days labour /t	171
Contribution to cost	% COSTS	% GER	Kg/labour day	5 85
Operating	72%	100 0%		
Total	48%	97 0%		

* sensitivity multipliers for financial and energy inputs
** Output costs and GER are calculated for whole fish, edible meat and protein % meat and protein weight from adapted from TDRI (1981): this source gives 40% and 8%dress-out for meat, protein respectively:
this is increase here as a larger proportion of the fish is consumed by rural people in Malawi

Annex 7 Financial and energy analysis of long line culture of marine mussels (*Mytilus edulis*) in Scotland: Presentation of model and assumptions.

A7.1 Introduction

The culture of shellfish ranges from simply seeding the sea bed with juvenile stock to the provision of artificial substrate or enclosures and protection from predators. Sources of stock include natural spat-fall in the culture environment, spat collection from other areas, juveniles from artificial hatchery systems. Growth of stock is achieved (in all cases except a few small experimental systems) from the natural productivity of the culture environment. In this respect shellfish production can be classified as extensive aquaculture. However, when considering other aspects of production, such as requirement for capital facilities and equipment, density of the culture organism, inputs of labour and management effort, these culture systems can be considered to represent a range of levels of intensity.

The Scottish mussel farming industry was chosen for ease of access to, and accuracy of, production data which were collected during visits to farms, discussions with farmers and suppliers to the industry and published sources. The success of mussel cultivation can vary greatly with the site of the operation. Variables which influence productivity and /or costs include:- the level of natural spat-fall, the rate of mussel growth, the liability to fouling or predation, the exposure to adverse sea conditions, and the ease of access to the site. The distance from markets, the degree of market development, the scale of the operation, the level of mechanisation, and the extent to which this activity is complementary with other activities of the operator will also influence the potential financial results (HIDB, 1989). The principal methods for mussel cultivation practised in Scotland both involve off-bottom culture on hanging ropes, suspended from either buoyed headlines (the cheapest and most common method) or rafts. The model presented examines the former.

The spreadsheet model developed for this system is presented in Annex. 7 Table 1. followed by notes providing background information on specific assumptions. More detail of the model structure and general assumptions are presented in Annex 2 and 3.

Notes

I Outline specifications

1. **Production**: 100t per annum, farm gate price £525/t; market price, including packaging and transport, is £600/t. See note 18 for details.

2. **Financial assumptions:** Discount and interest rates- see Annex 2. Grants and Finance: This case study allows for capital grants and loans as most mussel farms in Scotland have benefited from such financial assistance. The base case analysis includes grants of 50% investment capital, and 25% working capital for 2 years (HIDB, 1989)

II Capital Inputs.

3. **Long lines.** These consist of 220m head ropes (24mm polypropylene), supporting 6m long "down lines" (10mm polypropylene) spaced at 0.5m intervals along the head rope. One such head rope will produce approximately 15 tonnes of mussels over a two year cycle. To produce 100 tonnes per annum, 14 head ropes will be required.

4. **Mooring and floatation.** Mooring is provided by steel anchors and chain, as specified (lower cost systems can be used, but increase the risk of stock losses during storms). For floatation second hand plastic industrial fluid containers can be used, but here it is assumed that custom made polyethylene floats are used. These will have a longer life and are less liable to sun damage or collapse under heavy loads. Each buoy supports part of two head ropes, and 32 buoys are required for each pair of head-ropes.

5. **Equipment** includes a hoist, a petrol generator, a mechanical declumper (for separating mussels before grading), a grading table, and miscellaneous items such as waterproof clothing, bins, scales etc.

6. **Boat and working platform**. Equipment is installed on a simple work platform, comprising a wooden hull and floor, filled with polystyrene for buoyancy. Fittings for an outboard motor are provided. A one tonne steel dory with 2 * 25hp outboard motors (one as backup) is assumed.

7. **Shore facilities**. These can vary greatly. For a relatively large operation it is assumed that some basic shore facilities will be required, including a concrete jetty, a small packing shed and office.

8. **Vehicle:** A second hand pickup is included. It is likely that the vehicle would not be used solely for mussel farming activities. As such the relatively small cost is attributed to this item. For the energy analysis, a reduced quantity of materials is registered for the vehicle to reflect the proportion of the manufacture cost already accounted for by some other activity.

9 **Transport:** The financial cost of transport of capital items to site is included in the costs quoted. The energy cost of this is discussed in Annex 3.

III Operating inputs

10. **Stock and feed**: Mussel culture relies on natural spat-fall to supply the stock (assumed to be sufficient at the operation site) and natural productivity of the surrounding waters for stock growth. These items have no cost in terms of cash or energy as defined in this analysis.

11. **Labour**. Mussel farming is normally an owner operator activity, and as such the salary drawn will be dependant on the performance of the business. For the purposes of this analysis, however, it is assumed that the site is operated buy a site manager and one full time labourer (250 days per year), at specified salaries.

12. **Fuel and power:** Fuel requirements for boats and vehicles will vary greatly with the location of the site (i.e. distance by sea from shore base). Power required for land base will also vary with the organisation of the operation (use of pumps, office facilities heating etc) but will be generally low. The figures used are thought to represent reasonable estimate for an average site.

13 **Office costs:** includes stationary, phone, postage etc. Energy costs are assumed to be insignificant.

14. **Marketing**: This includes packaging, consisting of net bags (sold in 1,2, 5 and 10kg) labels for the small sale packs for retail sale, and transport to major markets. In the base case model for energy analysis, packaging is included, as for the salmon case, but transport is not. The importance of the latter item to the total GER are illustrated below. Packaging and transport costs are £30/t and £40/t respectively. GER of packaging is based on 5kg polyethylene/t output. GER of transport is discussed below.

15. **Transport**: This item does not include transport provided by the company vehicle, or replacement of capital items as these items are included in other assumptions (capital costs, note 9, fuel and maintenance, notes 12 and 17). The only significant requirement for transport as an operating input is for marketing. In the base case of the model, farm gate production costs are used, and a lower market price is assumed. The GER of transport to markets assumes an average round trip of 600km @MK 4 /km/tn = 2.4 MJ/ kg for transport to market (increase the GER of whole product by about 50% that of the base case).

16. **Site lease.** Standard fee of £50 per site payable to the crown estates.

17. **Maintenance and insurance** of facilities, equipment and vehicle: These are calculated as a percentage of total capital costs. Legal and professional services are set at a fixed rate.

18. **Output and revenues:** A steady state output of 100 tonnes per annum is assumed. Production of 50 tonnes will be achieved by the end of year two, and full production will be reached in year 3. A farm gate market price of £525 per tonne is assumed in the base case (HIDB). A market price of about £600/t quoted by one scottish producer included marketing costs detailed above, which is not included in the base case financial model.

19 **Summary**. The total output of mussels includes the shell weight. Edible wet weight of meat represents 40% of the total harvested weight (varies with season and condition of mussels). The protein content of meat is about 10% (TDRI, 1981).

Annex 7. Table 1. FINANCIAL AND ENERGY ANALYSIS OF LONG LINE MUSSEL CULTURE.
Source: Data from commercial operators, producers organisation and suppliers to the industry in Scotland

OUTLINE SPECIFICATIONS

Notes	1	Annual production (tonnes)	100	85 Ten year average
		Market price (per kg)	0.525	Not including selling costs.
		Meat as % total wt	40	
		Protein % total	16.7	
		Transport, km & GER/t km	500	4 MJ/t km
	2	Discount Rate %	15	Labour/GER sensitivity
		Interest (real) %	8	0 MJ/day labour GER
		or opportunity cost capital		0 MJ/£ salary
		Grant on equipment %	50	1 (for NPV and IRR only)
		Grant working capital %	25	1
		Tax rate %	40	
		Sensitivity multipliers		
		Capital inputs	1	Adjusts total costs, annual depreciation and energy values
		Operating inputs	1	Adjusts operating costs and energy inputs
		Marketing costs	1	1 = include packaging costs
			0	1= include transport to market, at a full market price of £600 per tonne

Annex 7, Table 1 (cont) SUMMARY OF INPUT AND OUTPUT DATA
(page 5 of model)

OUTPUT	STEADY STATE Total		TEN YEAR AVERAGE** Total					
PRODUCTION (P, tonnes)	100		85					
MARKET PRICE (p; £/tn)	525							
REVENUE Ra, £ total	52500		44625					
INPUTS	FINANCIAL (£ Sterling) Steady state		FINANCIAL (£ Sterling) Average ten years		GER MJ Steady state		GER MJ Average ten years	
(sensitivity multipliers)*								
(Capital 1	£	%	£	%	MJ	%	MJ	%
* (Operating 1								
CAPITAL depreciation, Ca;m(a	6753	14.4	6753	15.0	197344	50.0	197344	50.0
OPERATING (total) Va:f(v)	33021	70.6	31370	69.8	197303	50.0	197303	50.0
INTEREST (cap & op) Ia:	6974	14.9	6842	15.2				
TOTAL costs Ta:	46747		44964		394647		394647	
Cost per kg whole fish***	0.47		0.529	107.3%	3.95 MJ/kg		4.64	115.4%
Cost per kg meat 40.0%			1.32				11.61 MJ/kg	
Cost per kg protein 4.0%			13.22				116.07 MJ/kg	

** INVESTMENT APPRAISAL					Sensitivity analysis factors		
Discounted @		15.00 (10Years)	Grants			% Base Case for 10 year average	
NPV	£	2668	Capital	50%			
IRR	%	16.68%	Working, yr 1&2	25%	Unit production costs	0.53	107.3%
					Unit production GER	4.64	115.4%

Labour requirements (steady state)	
Operating labour, days/yr.	500
Days labour /t	5.88
Kg per labour day	170

* sensitivity multipliers for financial and energy inputs
** 10yr ave allows for buildup in production over first 2 years
*** meat content and protein content from TDRI (1981)

Annex 7 Table 1. (cont) FINANCIAL AND ENERGY ANALYSIS OF LONGLINE MUSSEL CULTURE (page 2 of model)

									SPECIFIC GER OF COMPONENT MATERIALS (m'(k))														
							Material identifier	(k) =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
									VEHICLES MOTORS	STEEL manufact	Aluminium	HDP PVC	P-ethylene	LDP P-styrene	P-propylene	Nylon	GRP	BUILDING	CONCRETE	EARTH MOVING	EARTH MOVING	TIMBER BAMBOO	OTHER 5
							Units		kg	kg	kg	kg	kg	kg	kg	kg	kg	per sqr m	/m^3	/m^3	/hour	kg	
							GER MJ/unit (m'k)		85	85	320	130	105	144	125	175	80	1200	2760	23	500	9	0
							sensitivity multipliers		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	CAPITAL INPUTS		Financial costs C (£sterling) Energy, GER, m (MJ)						QUANTITY OF COMPONENT MATERIALS m"(ijk) (kg)														
Notes	ITEM (i) Class	NO ITEMS (n)	COMPONENTS (i) per item	SPECIFICATIONS per item	COST C(i) per item	COST C(i)n Total	LIFE (T(i)) years	ANNUAL DEPRETN C(i)n/T (STR LINE	VEHICLES MOTORS	STEEL	ALUMINIUM	HDP PVC	PLASTICS P-ethylene	LDP P-styrene	P-propylene	Nylon	GRP	BUILDING per sqr m	CONCRETE m^3	EARTH MOVING m^3	EARTH MOVING /hour	TIMBER BAMBOO kg	OTHER
	3 LONG LINES					0	1	0															
		14	Head rope	220 m of 24mm	100	1400	5	280							50								
				polyprop rope	100	0	1	0															
				6160		0	1	0															
		154	220m of 10mm polyprop rope	Down lines 6m spaced @ 0 5m on head	15	2310	5	462							10								
						0	3	0															
						0	10	0															
						0	10	0															
	4 MOORING	20	Anchors 100kg	Samson	218	4360	10	436		100													
						0	10	0															
*		20	Chain: 15m of and £100 per 15m length	25mm, @ 210k	100	2000	10	200		210													
						0	5	0															
		2	Rope, 2 @ 220 * 24mm pp		100	200	5	40							50								
						0	5	0															
*		224	Buoys, 16 per (32 per double)	headrope 150l p eth.	20	4480	10	448					10 5										
						0	5	0															
						0	10	0															
	5 GRADER/	1	Grader and declumper		2200	2200	10	220		40													
	DECLUMPER	1	Petrol generator		1000	1000	5	200	35														
	HOIST	1	For lifting ropes		1000	1000	10	100		50													
						0	10	0															
	5 MISC	1	Bins, water proofs, scales etc		1000	1000	2	500					20										
						0	10	0															
						0	10	0															
	6 BOATS	1	Work platform	(wood, p styre	2000	2000	10	200		100				50								200	
		1	Steel dory		2000	2000	10	200		1000													
		2	Outboard 25hp		1600	3200	3	1067	50														
						0	10	0															
						0	10	0															
	SHORE FACILITIES					0	10	0															
	7 JETTY	1	Concrete	60m^3		3000	10	300											60				
						0	10	0															
	7 BUILDINGS	1	Packing shed	100m^2)		0	10	0															
		1	Office etc	50m^2)	20000	20000	20	1000										150					
						0	10	0															
		1	Furnishings etc		1000	1000	10	100															
						0	10	0															
	8 VEHICLES	1	Pickup	2nd hand	3000	3000	3	1000	600														
						0	5																
	9 TRANSPORT		Capital items to site			0	10																
	CAPITAL INPUTS Financial summary		TOTAL COSTS	Ct		54150																	
			Annual capital depretiation; Ca					6753															
			Interest on capital (@ 100% borrowing)			4332																	
	Energy input summary																						
			Capital GER per year MJ m(a) (AR73)			197344																	
			Capital GER per tonne output MJ (AR74) [m(a)/P]			1973																	

Annex 7 Table 1 (cont) FINANCIAL AND ENERGY ANALYSIS OF LONGLINE MUSSEL CULTURE (page 3)

TOTAL GER OF EACH COMPONENT MATERIAL IN [m(ijk)n)=m'(ijk)m*(ijk)n]

VEHICLES MOTORS	STEEL	ALUMINIUM	PLASTICS HDP PVC	PLASTICS P ethylene	LDP P styrene	P propylene	Nylon	GRP	BUILDING per sq m	CONCRET m^3	EARTH MOVING m^3	EARTH MOVING /hour	TIMBER BAMBOO kg	OTHER	TOTAL GER component ave annual (m( )n= Sum m(jk)n]	GER / YR component ave annual (m( )n/T]	Transport Total wt/life of items kg yr
															0	0	0
0	0	0	0	0	0	87500	0	0	0	0	0	0	0	0	87500	17500	140
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	192500	0	0	0	0	0	0	0	0	192500	38500	308
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	170000	0	0	0	0	0	0	0	0	0	0	0	0	0	170000	17000	200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	357000	0	0	0	0	0	0	0	0	0	0	0	0	0	357000	35700	420
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	12500	0	0	0	0	0	0	0	0	12500	2500	20
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	246960	0	0	0	0	0	0	0	0	0	0	246960	24696	235
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3400	0	0	0	0	0	0	0	0	0	0	0	0	0	3400	340	4
2975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2975	595	7
0	4250	0	0	0	0	0	0	0	0	0	0	0	0	0	4250	425	5
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2100	0	0	0	0	0	0	0	0	0	0	2100	1050	10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	8500	0	0	0	7200	0	0	0	0	0	0	0	1800	0	17500	1750	15
0	85000	0	0	0	0	0	0	0	0	0	0	0	0	0	85000	8500	100
8500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8500	2833	33
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	165600	0	0	0	0	165600	16560	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	180000	0	0	0	0	0	180000	9000	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51000	17000	200
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		3395	

TOTAL ANNUAL GER OF CAPITAL ITEMS (MJ) [Sum 197344
TOTAL CAPITAL GER PER TONNE OUTPUT (MJ) = 1973
Transport GER per MJ/t km ------ 4
: Distance km ------ 500
: Annual weight t ------ 1 70
: Total annual GER transport = 3395

CALCULATION OF ADDITIONAL CAPITAL EXPENDITURE DURING PROJECT LIFE

Year	1	2	**	3	**	4	**	**	5	**	6	**	**	**	7	**	8	**	**	**	9	**
Replace item if life =	1	2	1	3	1	4	2	1	5	1	6	3	2	1	7	1	8	4	2	1	9	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	*****	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	*****	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	200	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	*****	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*****	0	0	0	0	*****	0	0	0	0	0	*****	0	0	0	0	0	*****	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	*****	0	0	0	0	0	0	0	*****	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	*****	0	0	0	0	0	0	0	*****	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*****	0	*****	0	0	*****	0	*****	0	0	*****	*****	0	0	0	0	0	*****	0	0	0

Additional capital inputs

Year	1	2	3	4	5	6	7	8	9
Capital£	0	*****	*****	*****	*****	*****	0	*****	0

Annex 7 Table 1. (cont) FINANCIAL AND ENERGY ANALYSIS OF LONGLINE MUSSEL CULTURE (page 4)

OPERATING INPUTS

ITEM (i)	Quantity of item f*(i)	Units	Specifications	FINANCIAL BUDGET Cost/unit V(i)	Financial costs: V (£sterling) Total cost/item V(i)f*(i)	% Total Cost	ENERGY BUDGET Energy cost MJ/Unit f'(i)		GER, f (MJ) Energy cost MJ/item f=f'(i)f*(i)	% Total Energy	Sensitivity multipliers for GER
10 FEED	0	natural feeding		0	0	0.00	0		0	0.00	1
10 STOCK	0	natural spatfall		0	0	0.00	0		0	0.00	1
	0				0	0.00	40	0	0	0.00	1
					0	0.00			0	0.00	1
				0	0	0.00			0	0.00	1
					0	0.00			0	0.00	1
11 LABOUR	1	person (250 days)		8000	8000	24.23	0	(13MJ/day)	0	0.00	1
11 MANAGER	1	person (250 days)		15000	15000	45.43	0	"	0	0.00	1
	0				0	0.00	0	"	0	0.00	1
					0	0.00	0	(or GNP/ene	0	0.00	1
12 FUEL	2500	litres petrol	boat/pump etc	0.45	1125	3.41	40		100000	50.68	1
	1000	litres petrol	pickup	0.45	450	1.36	40		40000	20.27	1
12 POWER	1000	KWhrs	for land base	0.05	50	0.15	3.6		3600	1.82	1
					0	0.00			0	0.00	1
13 OFFICE COSTS	1	lump sum	Statnary, phone	1000	1000	3.03	0		0	0.00	1
					0	0.00			0	0.00	1
14 MARKETING:	1	0			0	0.00		5kg PE/t @	0	0.00	1
PACKAGING	100	tonnes output	net bags, labels	30	3000	9.09	525	105MJ/kg	52500	26.61	1
15 TRANSPORT	0	Tonnes mussels to market		40	0	0.00	2000	(4MJ/tn/km)	0	0.00	1
					0	0.00			0	0.00	1
INSURANCE, MAINTENANCE, LEGAL AND PROFESSIONAL					0	0.00			0	0.00	1
16 SITE LEASE	1	Fixed rate	Crown Estates	50	50	0.15	0		0	0.00	1
17 INSURANCE stk	100	tonne output	cost per tonne	10	1000	3.03	0		0	0.00	1
					0	0.00		Capital E	0	0.00	1
17 INSURANCE cap	51150	* capital cost of facilities		0.02	1023	3.10	0		0	0.00	1
17 MAINTENANCE	51150	* and buildings		0.02	1023	3.10	0.02	1535785	1023	0.52	1
					0	0.00	0		0	0.00	1
17 VEHICLES	3000	* capital	Ins, maint	0.10	300	0.91	0.06	51000	180	0.09	1
					0	0.00			0	0.00	1
17 LEGAL&PROFNAL	1	fixed rate		1000	1000	3.03			0	0.00	1
		TOTAL OPERATING COSTS		£ Sterling	33021	100			197303	100	
17 COST OF CAPITAL		(for unit production cost calculations)									
INTEREST on £	54150	investment capital @ % rate		0.08	4332						
INTEREST on £	33021	working capital @ % rate		0.08	2642						

		TOTAL COST OF CAPITAL			6974						

18 OUTPUT AND REVENUES	steady state tonnes	Year 0	1	2	3+	TOTAL 10yea	Ave 10years
ANNUAL PRODUCTION: tonnes	100	0	0	50	100	850	85
Market price (Wholesale/kg)	0.525		0	0	0		
REVENUE	52500	0	0 0	26250	52500	446250	44625