AN OVERVIEW OF FRESHWATER SUSTAINABLE AQUACULTURE TECHNIQUES ON A RECLAIMED COALFIELD SITE

Stephen Bedford Clark: Director of Aquatic Ecology & Sustainable Aquaculture:

The Earth Centre, Killers Bridge, Doncaster Road, Denaby Main,
South Yorkshire, United Kingdom. DN12 4DY

ABSTRACT

The rehabilitation of industrial zones and in particular redundant coalfield areas is a serious problem throughout the Western Hemisphere.

The Earth Centre project based at Conisbrough, South Yorkshire, United Kingdom is currently exploring new methods of sustainable freshwater aquaculture for applications to environmental and economic regeneration.

Mining subsidence contributes to the creation of wetland habitats suitable for freshwater aquaculture and new pond construction can utilise coal waste material as a semi-impermeable membrane for lining fish ponds.

The treatment of toxic pollutants in the initial culture water is by methods of engineered ecological filtration with the utilisation of emergent water plants to remove contaminates from the source water.

Adopted integrated farming systems practising aquatic polyculture lead to the diversification of saleable items produced from the various organic waste streams and can assist in the promotion of local business initiatives.

INTRODUCTION

The Earth Centre comprises of a unique range of entertaining and educational projects concerning sustainable development that has been brought together on a 141 hectare ex-colliery mine site located in Conisbrough and situated in the Dearne Valley, South Yorkshire, United Kingdom.
Following a three year research and planning period, The Earth Centre has completed the first of a five stage development programme with a projected completion for the visitor attraction by the year 2000.

LOCATION OF AQUACULTURE OPERATIONS

Presently two principle sectors have been identified for aquaculture operations:

The 2.8 hectare **Aquaculture Centre** site is located on north bank area of the River Don and consists of lined earth ponds, and a combined productive hatchery and aquatic ecology visitor centre.

The **Circle Tip** is a newly created wetland system to consider cyclic fish and plant production in eco-sensitive areas and is located on a 4.7 hectare flood water retention area between the River Don and the Sheffield & South Yorkshire Navigational canal, 50 metres south-west of Denaby lock.

AIMS & OBJECTIVES

Aquaculture

The principle aims are to blend innovation, research, conservation and educational awareness into a common goal of aquatic sustainability and demonstrate this through a successful commercial enterprise. Aquatic species will be raised without need for chemical or antibiotics to control fish diseases and high protein feeds will be discouraged in favour of locally raised aquatic invertebrates.

Emphasis will be placed on the integration of aquaculture and agriculture, and research in topical areas of symbiosis for the production of foodstuffs. Principal native freshwater species will be farmed and alien cultured species assessed in relation to local environmental impact.

Wetlands

All new initiatives in the creation of wetland habitats will be assessed with regard to their sustainable value and the increase in local biodiversity without undermining existing native species.
A planned effective system of sustainable management and the enhancement of existing wetland habitats will be financed by the sales of aquatic species. These will be sensitively harvested in wetland areas with **balanced** conservation management in relation to human activities.

DEFINITION AND CLARIFICATION OF SUSTAINABLE AQUACULTURE

Semi-controlled Natural Aquaculture

Utilise existing and natural ponds and lakes for the semi-controlled extensive practice of aquatic product cultivation. This exploits natural food chains and water re-cycling processes.
Although this method is environmentally friendly, it could not however sustain future global aquatic product and land management requirements.

Definition of SUSTAINABLE AQUACULTURE

Sustainable aquaculture is a dynamic process, not fixed; incorporating research, learning and reassessment of methods to practice and retain natural equilibrium in aquatic ecosystems. In controlled aquatic vegetation zones aquatic species are cultured at reasonable stocking densities and maintained with natural food products and compounds. Water quality is conserved by eco-technological methods and where applicable the need to utilise organic compounds and competent materials that are sensitive to the environment without interference in natural ecosystems.
The objective is to sustainably produce and keep pace with society's food requirements without eroding natural capital. This will be accomplished by the integration of new technologically initiated methods and combined with effective traditional practices.
The long term aim is to produce high quality organic freshwater fish products for local markets. The positive attribute of this strategy is less expense, environmental damage caused by evasive packaging, refrigeration, transport, energy and waste associated with them.

Intensive Non-Sustainable Aquaculture

Practices' methods of aquaculture within an artificially controlled environment, achieving substantial production rates by unnaturally high stocking densities and intensive supplementary feeding. This system also relies upon extensive fresh water circulation and additional synthetic chemical and antibiotic requirements. Profitable cultivation is at the expense of humane animal husbandry and ecosystems.

SITE EVALUATION & DESIGN

The site comprises of damaged former colliery land interlaced with fine ecologically diverse habitats embracing woodland, rivers, wetlands and magnesium limestone outcrops. Three major water courses traverse the land namely The River Don, The River Dearne and the Sheffield & South Yorkshire navigational canal with dispersed pockets of wetland habitat throughout the site.

i) **THE AQUACULTURE CENTRE**

Characteristics

Quite by chance the location is positioned approximately 700 metres south-east from the site of a series of 18th Century fish ponds at the village of Skitholme now buried under the large coal waste area adjoining the west bank of the River Dearne. The 5.6 hectare Phase One North sector of the site it was previously utilised for coal tipping and slurry ponds. The existing soil structure beneath the floodplain comprises of 3.0m of made ground consisting of grey sand, gravel, ash, silt, clay and other fragments of building materials.

Water quality sample statistics

River Don water quality analysis **(**source Yorkshire Water Authority)

The River Don sample point at Mexborough Power Station (01/01/93 to 31/12/93)

Element	**Units**	**Minimum**	**Maximum**
Lead total	UGH/L	4.49	11.1
Water temperature	Celsius	5.0	18.5
Oxygen Dissolved	%saturated	53.0	105.0
Oxygen Dissolved	MG/L	5.0	13.4
PH		6.03	7.63
BOD Total	MG/L	2.1	10.1
Suspended Solids	MG/L	7.0	131.0
Nitrate	MG/L	3.05	12.36
Ammonia Unionised	MG/L	0.0001	0.051
Chloride	MG/L	61.80	249.0
Phosphate	MG/L	0.12	2.14
Magnesium total	MG/L	11.6	25.3
Anionic detergent	MG/L	0.08	0.36
Cadmium total	UG/L	0.1	0.508
Copper total	UG/L	5.32	13.3
Zinc total	UG/L	26.0	65.0
Chromium total	UG/L	2.06	7.27
Iron total	UG/L	535.0	1210.0
Nickel total	UG/L	25.6	92.4

River Dearne water quality analysis

The River Dearne sample point at Pastures Bridge (01/01/93 to 31/12/93)

Element	**Units**	**Minimum**	**Maximum**
Lead total	UG/L	1.69	10.7
Water temperature	Celsius	3.0	18.0
Oxygen Dissolved	%saturated	56.0	100.0
Oxygen Dissolved	MG/L	5.4	12.8
PH		6.09	7.82
BOD Total	MG/L	2.7	11.1
Suspended Solids	MG/L	5.0	248.0
Nitrate	MG/L	5.65	14.45
Ammonia Unionised	MG/L	0.0001	0.0101
Chloride	MG/L	67.0	286.0
Phosphate	MG/L	0.13	2.46
Magnesium total	MG/L	12.2	46.4
Anionic detergent	MG/L	0.07	0.33
Cadmium total	UG/L	0.1	0.288
Copper total	UG/L	5.52	19.9
Zinc total	UG/L	20.0	49.0
Chromium total	UG/L	1.0	4.34
Iron total	UG/L	551.0	3910.0
Nickel total	UG/L	9.01	16.8

Summary of water quality analysis

The Rivers Don & Dearne has been historically polluted since the onset of the 19th Century Industrial Revolution. Up to a period of seven years ago the rivers where evaluated as Class 4 (poor quality) water courses. Presently they exist as Class 3 rivers and expected further improvement will attain a Class 2 (fair quality) status by 1996. Both rivers contain a high incidence of iron and other heavy metals due to mine water seepage. To accurately assess river bed pollution and the safe disposal of basal dredgings further analysis of river sedimentation is required.

Aquacultural design considerations for the centre was given to the following points:

1. Higher normal levels of heavy metals including Arsenic, Cadmium, Copper, Nickel, Zinc and water soluble Boron in the existing ground.

2. A 1.5 metre rise in flood water from the River Don based on a one in hundred year flood event.

Engineering specifications

To comply with the above points the ground level was raised by 1.5 metres by the importation of and compaction of 250mm layers of silty-sandy clay. Twelve engineered nursery ponds featuring an average surface area of 300 square metres were constructed using sustainable materials including bentonite lining and bezinal coated gabions infilled with aggregate.

Water circulation and treatment

Water is extracted at a rate of 1000 litres per minute from The River Don by using an ex-colliery, diesel generated pump. Future research will focus upon the feasibility of converting the pump to a renewable energy powered system that could possibly comprise of solar, wind or biogas driven energy.
River water travels via 110 metres of 10cm diameter steel pipe to the inlet reed bed.

The Vertical Flow Reedbed

Once completed the four beds will cover 1000 m2. Each bed is in operation for one day and then drained and allowed to rest for the next three days before being used again. The beds are 0.6 m deep with pea gravel on the surface and limestone gravel underneath. The water is sprayed onto the bed from surface pipes and trickles down through the gravel to the drainage pipes underneath. As the water passes over the surface of the gravel the bacteria consume many of the pollutants and any suspended particles present in the water are filtered. The water leaves the beds via the outlet pipe at the top of the stream.

The Open Water Channels

Reed bed cleansed water flows through open ditches designed to consider natural flow forms (or eddies that) reintroduce dissolved oxygen to the water, previously decreased by the biological action of the reed beds. The multi purpose ditchwork also creates a rich 'brook' type habitat with a variety of water plants and amphibians. Water insects are attracted to the running water and larvae swept into the culture foods to assist natural feeding regimes.

The Earth Ponds

Water circulation in the nursery ponds utilises a parallel delivery system where each pond is individually fed by clean water. The liquid fish waste returns via a separate circuit to flow into the outlet treatment lagoon. The benefits of a parallel method are the isolation of any outbreaks of fish diseases to an individual pond. In a 'series system' all the ponds are linked to the same 'flow through 'circuit. This shared water system, can quickly spread disease throughout ponds.

Outlet Water Treatment

Fish farming is a polluting industry and it is necessary to clean the water we use before being discharged back into the river. Treatment of outlet fish culture water is via settlement and a wetland horizontal flow ecological filtration process. This arranged in a natural wetland surrounding is to illustrate plant beds multi-functional purpose of water filtration, plant production and habitat conservation. The clean water in the lagoon can also be used to irrigate most of the site.

Biological design

The foremost biological pond design considers the combination of existing practical and productive aquacultural methods with the increased utilisation of natural aquatic food chains. The development of a controlled littoral (emergent aquatic plant) zone is a significant factor for the bio-structure of vegetable (phytoplankton) and animal (zooplankton) infrastructure. Not only does this provide a food source, but contributes to the breakdown of organic chemicals via bacteriological actions. Which in turn reduces toxic organic and chemical concentrations to acceptable water quality levels for freshwater cultured organisms.

The Hatchery and Aquatic Ecology Centre

Incorporates an attractive, practical design comprising of a 15m x 10m wooden building, partly below ground level with insulation and solar energy features. There is an extensive solar gain that contributes to the stimulation and growth of algae as a first stage fry food. The energy saving building design extends fry production facilities from six to twelve months.
River water is pumped to an external planted tank running the length of the building and a series of stop taps control the gravity feed and added aeration of water running to the internal tanks.

The internal, flexible working configuration, creates an opportunity for visitor observation to the developing stages of freshwater fish production.
The hatchery is also the base for pond dipping equipment from the adjacent 'community pond'. Here a variety of interpretative instruments such as microscopes, ‘touch and feel trough and literature both expressive and electronic can be found.

ii) **THE CIRCLE TIP SUSTAINABLE WETLAND SITE**

Characteristics

The underlying land was previously liable to extensive flooding and has over the years been raised with various spoil materials:
An average cross section is as follows:

Top soil	200mm - 300mm
Coal spoil (sandstone, coal fines, red ash slag, etc..)	500mm- 1100 mm
Sandy clay	greater than 2000mm

Engineering specifications

The overlying flat scrubland area was excavated with heavy machinery to an average depth of 500mm. The resultant spoil was transferred to create raised islands planted with trees and shrubs. A further 8000m2 of fish stock ponds was dug to an average depth of one metre and seeded with emergent plant species. Tests on the impermeability of coal spoil has indicated a figure of 10-9 m/sec relative to clay at 10 - 11 m/sec
Fringed areas were top soiled and left to naturally regenerate.

Biological design

The United Kingdom is rapidly losing wetland habitats due to land demand, loss of agricultural and commercial exploitation. Even where successful conservation schemes do exist the financial burden of maintenance must be met from dwindling funds. It has been recognised that a well-established wetland is said to be up to 50 times more productive than similar grassland and up to 8 times more productive than a similar area of cultivated land.
This innovative design considers eco-sensitive production and maintenance of conservation wetlands and is used to demonstrate to landowners that 'conservation does and can pay'.

While recognising the habitat requirements of a variety of plants, birds and animals - a series of fish ponds has been constructed in the wetland. Plants and fish can be sporadically harvested in this system and regular maintenance to the productive areas assists in discouraging the transition of wetland to terrestrial habitats.

METHOD OF CULTIVATION

The process of fish production is as follows:

1. Fish are bred in small outdoor and indoor breeding pools using natural duplication of environmental factors and other breeding techniques to stimulate natural reproduction.

2. The ova are transferred to the indoor hatchery, incorporates glass and suspended 'bag' tanks to view fry development. The feeding regime incorporating all stages of natural aquatic food.

3. Fingerlings (or young fish to a size of 5cm) are transferred to outdoor nursery pools and tanks or organically fertilised earth ponds for further growth.

4. Fish requiring a longer growing period to maturity or saleable sizes are transferred to the stock ponds in the 'Circle Tip' wetland area.

5. Saleable fish are transferred for processing, re-stocking or on site exhibition features.

DIVERSIFICATION AND MARKETING OF CULTURED FRESHWATER SPECIES

General

To achieve financial and productive sustainability the fish farm must achieve diversification of saleable products. It will need to culture a broad range of freshwater species and market these products within the food, leisure and ornamental industries as well as the exploitation of aquatic waste for greater efficiency in the system.

Food Products

Aquatic farmed products have been recognised as essential foodstuffs since the early Middle Ages. During this period many freshwater fish, now seldom cooked, would have been as highly prized as trout or salmon.

European and Asian markets already embrace the principle of the utilisation of freshwater species as food fish with carp (*Cyprinid* species) being extensively consumed.

New markets will be developed and capitalise on new (the Earth Centre cafe) and existing outlets (restaurants, specialist fishmongers and supermarkets) with detailed market research of alternative and historically resurrected species.

Leisure Industry

Recognising angling as a sporting pastime but promoting the need for controlled restocking of open waters and applied conservation strategies.
Liaison with water and angling institutions on a regional and national level will establish markets for quality re-stocking and educational support given to angling institutions who will contribute to environmental debates relating to fish husbandry.

Ornamental Fishkeeping Industry

There is a growing demand for quality live fish, particularly in the domestic pondkeeping sector and a policy has been adopted to raise standards and educate fishkeepers in correct animal husbandry. There will be a programme to increase awareness to the potential stress placed on fish due to poor environmental conditions and bad handling.

Aquatic Waste Products

Aquatic waste products in several industrial processes can be utilised. (That is organic fertilisers, fish oils, medicines, etc.). and the identification of substitute eco-friendly products to corresponding markets as alternatives to synthetic substances.

Integrated farming systems identify waste as a positive resource and organically based aquacultural waste utilised for horticulture, agriculture and forestry. The distribution of organic on-site waste will assist production and efficiency at the wider Earth Centre site.

and literature both expressive and electronic can be found.

ii) **THE CIRCLE TIP SUSTAINABLE WETLAND SITE**

Characteristics

The underlying land was previously liable to extensive flooding and has over the years been raised with various spoil materials:
An average cross section is as follows:

Top soil	200mm - 300mm
Coal spoil (sandstone, coal fines, red ash slag, etc..)	500mm- 1100 mm
Sandy clay	greater than 2000mm

Engineering specifications

The overlying flat scrubland area was excavated with heavy machinery to an average depth of 500mm. The resultant spoil was transferred to create raised islands planted with trees and shrubs. A further 8000m2 of fish stock ponds was dug to an average depth of one metre and seeded with emergent plant species. Tests on the impermeability of coal spoil has indicated a figure of 10-9 m/sec relative to clay at 10 - 11 m/sec
Fringed areas were top soiled and left to naturally regenerate.

Biological design

The United Kingdom is rapidly losing wetland habitats due to land demand, loss of agricultural and commercial exploitation. Even where successful conservation schemes do exist the financial burden of maintenance must be met from dwindling funds. It has been recognised that a well-established wetland is said to be up to 50 times more productive than similar grassland and up to 8 times more productive than a similar area of cultivated land.
This innovative design considers eco-sensitive production and maintenance of conservation wetlands and is used to demonstrate to landowners that 'conservation does and can pay'.
While recognising the habitat requirements of a variety of plants, birds and animals - a series of fish ponds has been constructed in the wetland. Plants and fish can be sporadically harvested in this system and regular maintenance to the productive areas assists in discouraging the transition of wetland to terrestrial habitats.

METHOD OF CULTIVATION

The process of fish production is as follows:

1. Fish are bred in small outdoor and indoor breeding pools using natural duplication of environmental factors and other breeding techniques to stimulate natural reproduction.

2. The ova are transferred to the indoor hatchery, incorporates glass and suspended 'bag' tanks to view fry development. The feeding regime incorporating all stages of natural aquatic food.

3. Fingerlings (or young fish to a size of 5cm) are transferred to outdoor nursery pools and tanks or organically fertilised earth ponds for further growth.

4. Fish requiring a longer growing period to maturity or saleable sizes are transferred to the stock ponds in the 'Circle Tip' wetland area.

5. Saleable fish are transferred for processing, re-stocking or on site exhibition features.

DIVERSIFICATION AND MARKETING OF CULTURED FRESHWATER SPECIES

General

To achieve financial and productive sustainability the fish farm must achieve diversification of saleable products. It will need to culture a broad range of freshwater species and market these products within the food, leisure and ornamental industries as well as the exploitation of aquatic waste for greater efficiency in the system.

Food Products

Aquatic farmed products have been recognised as essential foodstuffs since the early Middle Ages. During this period many freshwater fish, now seldom cooked, would have been as highly prized as trout or salmon.

European and Asian markets already embrace the principle of the utilisation of freshwater species as food fish with carp (*Cyprinid* species) being extensively consumed.

New markets will be developed and capitalise on new (the Earth Centre cafe) and existing outlets (restaurants, specialist fishmongers and supermarkets) with detailed market research of alternative and historically resurrected species.

Leisure Industry

Recognising angling as a sporting pastime but promoting the need for controlled restocking of open waters and applied conservation strategies.
Liaison with water and angling institutions on a regional and national level will establish markets for quality re-stocking and educational support given to angling institutions who will contribute to environmental debates relating to fish husbandry.

Ornamental Fishkeeping Industry

There is a growing demand for quality live fish, particularly in the domestic pondkeeping sector and a policy has been adopted to raise standards and educate fishkeepers in correct animal husbandry. There will be a programme to increase awareness to the potential stress placed on fish due to poor environmental conditions and bad handling.

Aquatic Waste Products

Aquatic waste products in several industrial processes can be utilised. (That is organic fertilisers, fish oils, medicines, etc.). and the identification of substitute eco-friendly products to corresponding markets as alternatives to synthetic substances.

Integrated farming systems identify waste as a positive resource and organically based aquacultural waste utilised for horticulture, agriculture and forestry. The distribution of organic on-site waste will assist production and efficiency at the wider Earth Centre site.

2. Freshwater Aquaculture

Sustainable Aquaculture Design

In the context of the previous definition of sustainable aquaculture to embark on a general study and relative modeling of species specific culture and polyculture. This will consider the relationship on of aquacultural design to topographical, hydrological, biological and engineering conditions in varying habitats. The utilisation of eco-friendly heat sources for increased growth rates.

Diversification of cultured species

To research a diverse range of aquatic species and study the reproductive biology and local conditions of aquatic animals and plants for suitability to aquacultural operations. Aquatic organisms to be considered are algae, zooplankton, aquatic worms, snails, fish (coldwater and warmwater species) and amphibians.

To research a diverse range of aquatic species and study the reproductive biology and local conditions of aquatic animals and plants for suitability to aquacultural operations. Aquatic organisms to be considered are algae, zooplankton, aquatic worms, snails, fish (coldwater and warmwater species) and amphibians.

To research a diverse range of aquatic species and study the reproductive biology and local conditions of aquatic animals and plants for suitability to aquacultural operations. Aquatic organisms to be considered are algae, zooplankton, aquatic worms, snails, fish (coldwater and warmwater species) and amphibians.

Ecological filtration techniques

The application of varying design parameters, efficiency of varying plant species and methods of plant filtration on water flow rates. To study the relationship of water borne pollution and regulatory standards on differing models of ecological filtration and the environmental impact of aquaculture operations on specific habitats. Uses of aquatic sludge in other bio-remedial processes.

Ecological methods of fish disease control

Research and experimentation on intensifying specific animals in the native aquatic food chain for the predation and control of freshwater fish diseases.
Application for the use of herbal remedies on aquacultural operations.

Breeding and rearing methods

Identifying ecological methods for the induced spawning and the analysis of the species specific nutritional requirements for fish raising without reliance on artificial feed.