Artificial reefs on the west coast of Scotland

Wilding, Thomas; Sayer, Martin

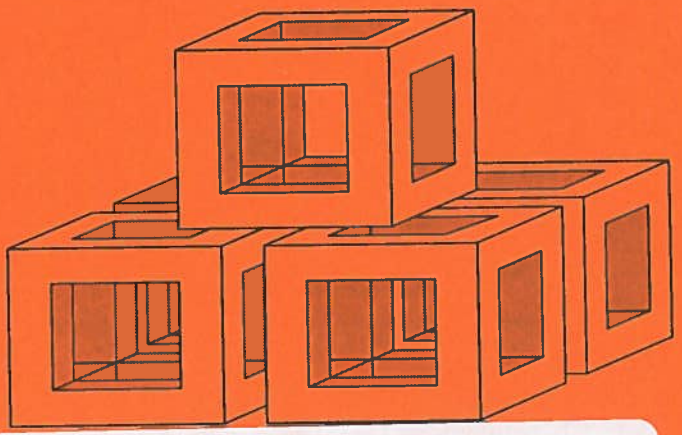
Publication date:
1996

ARTIFICIAL REEFS ON THE WEST COAST OF SCOTLAND: A FEASIBILITY STUDY

FINAL REPORT TO THE MARINE RESOURCE INITIATIVE

T.A. WILDING and M.D.J. SAYER

December 1996



DML
INTERNAL REPORT
203
1996

Dunstaffnage Marine Laboratory
P.O. Box 3, Oban
Argyll PA34 4AD

ARTIFICIAL REEFS ON THE WEST COAST OF SCOTLAND: A FEASIBILITY STUDY

REPORT TO THE 'MARINE RESOURCE INITIATIVE'

BY THOMAS A. WILDING AND MARTIN D. J. SAYER
DUNSTAFFNAGE MARINE LABORATORY
P. O. BOX 3
OBAN
ARGYLL
PA34 4AD

TEL:- (01631) 562244
FAX:- (01631) 565518

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Executive Summary

Artificial reefs are man-made structures placed on the sea floor. They generally alter the characteristic of the seafloor in the local area by providing a substrate on which sessile organisms can grow and a refuge for mobile animals. They are used for a wide range of purposes and are constructed from a variety of materials.

Examples of the uses of artificial reefs include fisheries enhancement, habitat protection, coastal protection and recreation (diving and fishing). Examples of construction materials include quarry rubble, pulverised fuel ash, compressed cars, tyres, redundant oil rigs, decommissioned fishing vessels and purpose built concrete blocks.

The most contentious legal issue in Europe concerning artificial reef development is the matter of whether reef construction constitutes dumping. One view is that artificial reefs offer a new role for the construction material and therefore the placement of reef should not be considered dumping. The alternative opinion is that reef development is an excuse for dumping material in the sea which contravenes international regulations. The trend in Europe is towards the elimination of the sea as a receiving environment for waste products so the definition of reef building (dumping or construction) is very important and as yet remains unresolved.

On the west coast of Scotland interest in artificial reefs has been shown by various sectors of the business community. This includes quarry operators and power producers both of which are faced with expensive waste aggregate disposal problems. Their interest stems from the potential to utilise these products in reef construction. A single artificial reef could serve the needs of sport fishermen and be ideal for lobster ranching, the attributes of a reef built for either of these functions being broadly similar.

The feasibility study has shown that:

- the construction of the reef could utilise waste products which would otherwise pose an expensive waste disposal problem;
- an artificial reef development could catalyse the growth of sport fishing and provide a basis for lobster ranching.

The feasibility study recommendations for further research are:-

- to determine the most cost effective method of utilising quarry and/or power production by products in the manufacture of durable blocks suitable for use in reef construction.
- to determine the economic viability of a reef development (in terms of the cost of block manufacture and deployment against reef benefit such as income from sport fishing, lobster ranching and waste utilisation).
- to search for a suitable reef site which would allow both sport fishing and lobster ranching.

CHAPTER 1. INTRODUCTION

This work has been commissioned by the Marine Resource Initiative (MRI) and conducted at the Dunstaffnage Marine Laboratory (an associate member of the European Artificial Reef Research Network (EARRN)).

The main objectives of the study are to assess the socio-economic benefits that might occur as a result of an artificial reef development, to identify the potential users of an artificial reef and to examine the possible construction materials for an artificial reef on the west coast of Scotland. It has been necessary to consider the legal implications for reef development and the requirements of licencing as part of this work. In this important respect the findings are applicable to the whole of Scotland.

The information gathered during the research phase of this feasibility study has come from two main sources. Published literature has been examined for background information whilst issues relevant to Scotland have been addressed through personal contacts with relevant organisations. This has included contacts with the Scottish Office who would have to licence any reef development, environmental agencies such as the Scottish Natural Heritage, industries producing inert waste aggregates which have potential in reef manufacture, businesses who are potential users of artificial reefs and academic institutions concerned with waste management and lobster ranching.

The following sections are followed by a short summary where it is considered useful. It is the aim of this report that an overview of the subject of reef development can be obtained by reading these summary sections. For those who require more detail it can be found in the main text whilst the bibliography indicates sources of further information.

CHAPTER 2. ARTIFICIAL REEFS

This chapter summarizes briefly the purposes, uses and construction materials of artificial reefs that have previously been deployed. It also describes some of the legislation (both in a national and international context) that governs the placement of artificial reefs on the sea floor and legislation concerning fisheries ownership.

SECTION 2.1 What is an artificial reef?

An artificial reef is a man made stationary structure placed on the sea floor. It can be constructed from a variety of materials and have a variety of functions. Artificial reefs and fish attracting devices have been used for many centuries. The idea of constructing an artificial reef probably results from the observation that fish are attracted to structures floating or suspended in the water column (a fish attracting device) or on the sea floor (artificial reef). Both structures enhance the local fishery and are perceived as beneficial.

SECTION 2.2 The uses of artificial reefs

The uses of artificial reefs are numerous, many have more than one function (in the UK, the Ministry of Agriculture, Fisheries and Food favour the development of multi-purpose reefs). A list of some of the various uses of reefs are shown in table 1.

Table 1 A summary of some uses of artificial reefs

Purpose of reef	**Details**
Fisheries enhancement/ increased biomass	Reefs can promote the development of sustainable fisheries, often specifically to assist small communities. The reef can be used to enhance the overall productivity of the area.
Coastal Protection	Reefs can protect vunerable areas of coast by acting as a barrier to wave action or by inducing the breaking of a wave and thereby reducing destructive wave energy reaching the shoreline.
Control of fishing access	Reefs can used to prevent access to fisheries by certain fishing practices (generally this is trawling) where such activity is perceived as being detrimental and where such prevention of access has a legal mandate.
Nursery habitat formation/ marine reserves/ ecological restoration/ environmental damage mitigation/ nutrient capture	Reefs can benefit ecosystems by providing marine flora and fauna with a substrate to colonise. Habitat created can be designed to provide nursery habitats for certain species. Some organisms rectify damage done by man (ie the removal or bioaccumulation of pollution both inorganic and organic). Such areas can be set aside as marine reserves.
Recreation	Reefs can be constructed to enhance sport diving and sport fishing.
Scientific research	Reefs make ideal bases for scientific research as they enable the researcher to accurately control certain elements of the reef. Research has concentrated on colonisation rates and the transition of species. Further work needs to be conducted into habitat selection by reef organisms.

Subsection 2.2.1 Fishery enhancement

Fishery enhancement was probably the first use of artificial reefs and they are still widely used, particularly in the Far East, for this reason. There is debate as to whether the reef causes fish to congregate (thus basically concentrating existing fish stocks) or whether it actually increases overall productivity (thus increasing the fish stock). Either of these eventualities can result in a desirable increase in the fish catch per unit effort. Despite much research in tropical and semi-tropical areas this production versus aggregation issue remains unresolved at present. Little research has been conducted into this issue on temperate water reefs. Visual and camera observations have shown that fish are attracted to artificial reefs. However, seasonal and diurnal variation in fish numbers and the lack of scientific knowledge concerning the behaviour of particular species means that it is impossible to ascertain whether this attraction actually results in real increases in fish numbers. The alternative is that fish attracted to an artificial reef reduce numbers on neighbouring natural reefs.

In Japan artificial reefs have been used for thousands of years. There is an established programme in artificial reef research in that country. The priority of the Japanese reefs is to enhance and protect fisheries, seafood being an important part of the national diet. In addition to normal reefs where benefit results from the colonisation of the new substrate, new reefs are being designed and built to cause ocean up-welling. In this instance the reef is not acting as a substrate for encrusting organisms, rather it acts to increase surface productivity by forcing nutrient rich water to the surface.

Of particular relevance and interest to the west coast of Scotland is the use of artificial reefs in the ranching of lobsters. This is discussed in part 3.2.3.1.

Subsection 2.2.2 Coastal protection

Artificial reefs can be used to cause waves to break offshore by reducing water depth, thereby minimising wave energy reaching the coastline. One of the first reefs of this type in the UK was built in 1984 at Torness, Lothian. This reef is substantial and is, in part, constructed using the spoil produced during the

excavation of the Torness nuclear reactor site. The reef is 1000 m x 150 m and composed of 60 modules (91,000 cubic metres of rock weighing 210,000 tonnes) placed 3.4 km to the south east of Torness Point. Faunal and floral colonisation has been monitored and the reef has been shown to provide a good habitat for lobsters. For more information on this reef development see Todd (1992).

Other offshore reefs are under review, such as the one proposed between Happisburg and Winterton, Norfolk. This scheme involves the construction of 16 reefs, each 200 m long with a gap of 300 m between each reef. The reef will be situated 300 m off, and parallel to, the shore along approximately 8 km of coastline. Each reef will have a crest elevation of some 3 metres above low water. The materials to be used include a core of 1-2 ton quarried stone blocks with a capping of 8 - 20 ton blocks.

Subsection 2.2.3 Habitat protection

The deployment of artificial reefs to protect areas of the seafloor has been utilised mainly in Spain and other Mediterranean countries to enforce the legal protection of selected areas of *Posidonia oceanica* 'meadow'. This type of habitat has great ecological and fishery value and was being destroyed by extensive and repeated trawling. In the UK there is no legislation to enable the protection of areas of seabed and it is likely that ,until a change occurs, representations from the powerful fishing lobby will normally stop any licence to construct a reef being issued by the Scottish Office for this function (see subsection 3.1.1.).

A reef designed for habitat protection generally encloses the area designated for protection, the outer boundary reef being constructed of, for example, 10 to 15 ton concrete blocks from which redundant railway tracks project. The purpose of these exterior blocks and the reason for their size is to prevent their removal by trawlers. The projections entangle and shred trawl nets making attempted illegal fishing activity potentially very expensive for the fishermen. The inner part of the reef may contain further reefs with specific functions such as the enhancement of valuable species. The use of reefs for near-shore benthos protection has received support from artisanal fisheries which are damaged by large scale trawling activity,

especially in Mediterranean countries.

Subsection 2.2.4 Recreation

Recreational diving is a growing industry in the UK with membership of the main British sport diving clubs, namely the Professional Association of Diving Instructors (PADI), the Scottish Sub Aqua Club (ScotSAC) and the British Sub-Aqua Club (BSAC), showing continued growth. The BSAC estimates that in 1996 approximately 90,000 sport divers exist in the UK.

Artificial reefs have been utilised extensively in other countries to enhance or initiate sport diving activity. In Hawaii, for example, a $1M reef has been constructed using a mixture of Japanese style concrete terrace reefs, a redundant cargo vessel and 2 aeroplanes. The company owning the reef operates 2 small submarines which carry fee paying tourists. Recreational diving and fishing promoted by the reef also benefit the local economy. It has been estimated that the reef attracts some 20,000 divers per year to what was previously a barren expanse of sand and limestone bedrock.

Attempts have been made in the UK to use decommissioned fishing vessels for the construction of reefs. These projects have failed for a number of reasons some of which are discussed in subsection 3.3.3.

Recreational fishing is the basis for much of the development of the United States of America (US) artificial reef ('rigs to reefs') programme (see subsection 2.3.4). Such a programme resulted from the development of sport fishing around active oil rigs. Sport fishing is very under-developed on the west coast of Scotland because of several factors. These reasons, the developmental requirements and potential for the industry are discussed in subsection 3.2.2.

The promotion of sport angling and the extra revenue it would bring to local economies was the rationale for a artificial reef proposal by Aberdeen University Research and Industrial Services Ltd (AURIS Ltd). Site selection using 'geographical information systems' (GIS) and exclusion mapping (see subsection

3.4.1) identified a site in the Moray Firth. The proposed reef was to be constructed from a redundant tubular steel structure with a main purpose of enhancing sport fishing in an area with a declining commercial fishing fleet. This proposal has been withdrawn because of requirements made by the Scottish Office in implementing the licencing conditions of the Food and Environment Protection Act (1985) (see subsection 3.1.1.) and the non-returnable initial fee of £1000 for licence application assessment.

(2.2) Section Summary: The uses of artificial reefs

An artificial reef is a structure placed on the sea floor that can be used for a variety of purposes and built from a variety of materials. An artificial reef normally works by providing a hard substrate on which plants and animals can grow and/or providing a refuge for mobile species. It is through the establishment of biological communities that many of the reef functions operate. This includes fisheries enhancement, environmental damage amelioration and the promotion of recreational fishing and diving. Reefs can also act purely as a physical barrier. Examples of such uses include coastal protection where reefs cause waves to break offshore (thus reducing their impact on the coastline) and fisheries protection. In addition to their primary purpose such reefs often provide an excellent habitat for marine organisms.

SECTION 2.3 Artificial reef construction materials

This section provides a brief summary of the materials used in artificial reef construction. The choice of materials used in the construction of a reef can be dependent on the desired reef function, the resources available and/or any relevant legislation.

The choice of materials used in reef construction is considerable and ranges from relatively expensive purpose built concrete blocks to waste rubble and tyres which would otherwise have to be expensively land-filled. It is because artificial reefs can be built from waste materials that some view their construction as a 'licence to dump'. Potential reef construction materials identified during this feasibility study as having most relevance to the west coast of Scotland are discussed in section 3.3.

Subsection 2.3.1 Waste aggregates

The use of waste aggregates is particularly pertinent to the west coast of Scotland where numerous quarrying operations produce a large quantity of various aggregate waste products. This is discussed in subsection 3.3.1.

In addition to quarrying operations, waste aggregates are also produced as a result of the demolition of buildings, bridges etc. The inclusion of this type of material into the artificial reef may benefit the reef design by introducing a variety of refuge sizes depending on the rubble size. Given the increase in costs associated with the land fill option for waste disposal (as a result of the 'Land Fill Tax') the use of such materials in artificial reef manufacture may become more attractive to industries producing bulk inert waste products.

Subsection 2.3.2 Tyres

The disposal of tyres is a problem in many of the developed and developing countries in the world. Increasing concern over tyre fires and increasing costs of land-fill has resulted in their use for reef construction in many countries including the US, Australia and Cuba.

In Australia initial experimental reefs failed because individual tyres were

excavated by storms and the reef structures subsequently destroyed. Since 1984 Australian scrap tyres have been made into tetrahedron module units (TMUs) with concrete in the basal tyres as ballast. Twenty eight tyres are used in each TMU, 7000 such modules having been deployed in South Australian waters. The TMUs have been shown to retain structural integrity for over seven years and have had no adverse environmental effect. In the US, tyres are bound together (some are then compressed depending on the operator) and the central hollow filled with concrete to provide ballast. As the US has no central funds for the development of artificial reefs, the cost of the reef construction is met by local counties whose agents charge for tyre disposal. Cuba has an active tyre-to-reef policy. Monitoring of the reefs has shown that a typical reef community establishes in time and no toxic effects have been recorded (for further information on tyre reefs see Branden, 1994)

Subsection 2.3.3 Ash

Ash is produced in large quantities in Scotland by power generating companies producing electricity by burning coal. The potential and advantages of using ash are discussed in detail in section 3.3.2.

Subsection 2.3.4 Redundant oil production platforms/ oil rigs

The US has an active 'rigs to reefs' policy as a result of the perceived (there is limited scientific data on this issue) increase in sport fishing catches around oil production platforms in areas such as the Mexican Gulf and the coast of Louisiana. US oil production platforms and rigs are generally smaller and older than North Sea platforms but like North Sea platforms are unusual artificial reefs because they rise from the sea floor to the surface. Fish catches around these 'reefs' are commonly believed to be five times the number found per unit area on natural reefs in the US. The removal of production platforms from these areas in the US is not welcomed by sport fishermen or the local communities dependent on the income generated from sport fishing. Therefore there has been an active programme of converting rigs into artificial reefs. In the US, the State (predominantly Louisiana and Texas in this programme) assumes responsibility and liability for the platform/rig once it has been converted to a reef. The oil company donates 50% of

the saving made through using this disposal option to continue research into and maintenance of the artificial reef. In Louisiana nine artificial reefs have been constructed using twenty obsolete platforms. This method of use has proved to be very successful with profound socio-economic benefits to coastal communities.

In the UK the situation is very different. The oil production platforms are generally much bigger, lie in deeper water and are further offshore. There is no sport fishing industry keen to support a rigs to reef policy (no vessel is allowed by law within several hundred metres of the oil production platform or rig) and the political situation is more complex (viz. the Brent Spar). In addition the oil companies 'promised' to remove all structures from the sea floor for which they were responsible to placate a large commercial fishing lobby whose method of capture is generally trawling and who perceive that 'littering' the seabed with redundant structures would compromise their future ability to fish.

For a detailed analysis of the potential for converting rigs to reefs and progress made in this field in other countries see Jensen (1996).

(2.3) Section Summary: Artificial reef construction materials.

Artificial reefs can be and have been constructed from an enormous variety of materials. The selection of material is determined by a number of factors but includes material availability (the use of waste materials often makes economic sense), legal constraints and reef purpose. Reefs designed for recreational diving are commonly constructed from redundant ships whilst those designed for recreational fishing can be built using redundant oil rigs or purpose built concrete blocks (see later sections).

SECTION 2.4 Legal aspects of artificial reef deployment

This section concentrates on the legal issues concerning artificial reef placement that apply within the UK and Europe in general. Issues specific to the west coast of Scotland are detailed in section 3.1.

Subsection 2.4.1 International Conventions

The international conventions concerning artificial reefs are numerous, occasionally conflicting depending on interpretation and generally complex. It is not the intention of this report to give a complete review of the legal issues relating to artificial reefs. Instead, a general overview is presented. For a review of the European legislation governing artificial reefs see Pickering (1996).

The placement of materials to construct artificial reefs is considered dumping and, as such, is under international (European) legislation. The largest debate in Europe over artificial reef deployment concerns the perception by some that artificial reef construction is, in effect, a licence to dump materials at sea that are banned under international convention. Whilst dumping at sea is regarded as acceptable under certain circumstances there is a trend in the EU towards its complete elimination. The concerns of some nations that artificial reef construction is a mechanism to circumvent international conventions and the continuing acceptance and adoption of the precautionary principle in determining policy mean it less likely that artificial reef construction using waste materials will be permitted in the future. Indeed the Helsinki Convention (similar to the London Dumping Convention (see part 2.4.1.2) but applicable to the Baltic Sea area only) recommends the removal of all existing artificial reefs that are not in close proximity to urban areas. The broad scale adoption of the Helsinki Convention approach will severely limit the construction of artificial reefs and may even require their removal.

In general the rapid growth of interest in artificial reef development has outpaced the development of a legal framework by which to control and regulate projects. This has resulted in confusion and varied interpretation of regulations which often do not specifically mention artificial reef construction.

In brief the following list of international conventions apply to reef construction, some of these conventions are described in following sections.

- The United Nations Convention on the Law of the Sea III (UNCLOS III)(1982)
- London Convention on the prevention of marine pollution by dumping of wastes and other matter (1975) (London Dumping Convention)
- The Oslo convention for the prevention of marine pollution by dumping from ships and aircraft (1972)
- Convention for the protection of the marine environment of the NE Atlantic (1992)
- Declarations made at the second (1987) and third (1990) Conferences on the protection of the North Sea
- The Convention on the protection of the marine environment of the Baltic Sea area (1974) (Helsinki Convention)
- Convention for the protection of the Mediterranean Sea against pollution (1977) (The Barcelona Convention).

2.4.1.1 United Nations Convention on the Law of the Sea (1982). Sea dumping is defined by the 'United Nations Convention on the Law of the Sea (1982)' (UNCLOS III) as "any deliberate disposal of waste or other matter from vessels, aircraft, platforms or other man-made structures at sea".

UNCLOS III obliges signatories to the convention to protect the marine environment from pollution. Whilst it does make provision for the construction of artificial reefs it remains unclear as to how to define pollution. For example pulverised fuel ash (PFA) contains trace amounts of heavy metals for which sea disposal is banned under the London Dumping Convention (1975). Blocks manufactured using cement stabilised PFA have been shown to be durable in marine conditions and leaching of metals from the cement stabilised ash has not occurred. However, the metals remain in the PFA which, it is presumed, will eventually break up. There are, as yet, unresolved differences in interpreting whether the use of PFA contravenes either the London Dumping Convention or UNCLOS III.

Further ambiguity exists in the regulations under UNCLOS III. It allows oil companies to abandon parts of oil rigs (such as the jackets which hold the superstructure above the water) whilst forbidding the moving of such jackets and subsequent dumping. So leaving a jacket *in situ* and creating an artificial reef is permissible but moving the same structure to a more useful and productive site is banned. For a detailed description of this convention see the Greenwich Forum (1994).

2.4.1.2 London Dumping Convention (1975). In the London Dumping Convention waste materials are listed under black, grey or 'other' . Under this convention the sea disposal of black listed substances is prohibited, whilst those on the grey list can be dumped under special circumstances.

Under the London Dumping Convention allowance is made for artificial reef development. It states as permissible "placement of matter for a purpose other than the mere disposal thereof, provided that such placement is not contrary to the aims of the convention". This particular part of the convention has been adopted into UK law under the UK Waste Management Licensing Regulations (1994), where an item is considered waste if the dumping marks the end of that materials existence in the normal commercial cycle. Material, for example PFA blocks, actually utilised for another function (reef building) would therefore not be considered waste. However, as previously mentioned, PFA contains trace amounts of black list substances, whether the dumping of such material is contrary to the 'aims of the convention' is open to debate.

2.4.1.3 Convention for the protection of the Marine Environment of the N E Atlantic (1992). This convention replaces both the Oslo Convention for the prevention of marine pollution by dumping from ships and aircraft (1972) and the Convention for the prevention of Marine Pollution from Land Based Sources (1974) (Paris Convention). Whilst covering the same area as the previous conventions differs slightly from the London Dumping Convention in that it enacts a general ban on dumping and has adopted a list of exceptions. The N E Atlantic Convention is wider in scope and covers the affects of human activity on the marine

environment. It also differs from previous conventions in that it has adopted the ideals of the precautionary principle. Anyone engaging in dumping must have an action plan, under annual review, to eliminate pollution as a result of dumping.

2.4.1.4 Second (1987) and Third (1990) Conference for the Protection of the North Sea. During the second conference the concept of the 'prior justification procedure' was agreed. Administered under the Oslo Commission this concept requires that for any material to be dumped at sea there must be no practical alternatives on land and no adverse effects on the marine environment. This idea was further strengthened during the third conference when a general commitment was made to end all dumping of industrial waste at sea. The prior justification procedure requirement is a continuing move towards the precautionary principle approach to dumping industrial waste.

SECTION 2.5 Property rights

The adoption in 1609 AD of the doctrine of *mare libarum* by Holland and England was the historical precedent resulting in the fact that fisheries are given an open access status. This means that the fish in the sea belong to no-one until they are caught, only then are fish owned by the captor. This basis of ownership and exploitation rights within the marine environment is governed by the United Nations Convention on the Law of the Sea III (1982) (UNCLOS III).

The UK is unique in Europe in that it grants 'Several Orders' or 'Regulatory Orders' (by an order under the Sea Fisheries (Shellfish) Act, 1967) which over-turns the ancient right, adopted under the doctrine of *mare libarum*, of the freedom to fish. It gives ownership (property rights) of certain species of shell fish even as they remain uncaught on the sea floor. This transfer of property rights from no-one to someone means that it becomes a criminal activity to take named species from within the boundaries of the Several Order without permission from the owner. Anyone caught doing so can be prosecuted under criminal law. The Several Order defines an area of sea bed where the change in rights occur. To gain a Several Order, permission must be given by Parliament; this process is lengthy. At present the Several Order protects certain bivalves (scallops, mussels, oysters and cockles)

from an open access fishery. There are two Scottish scallop ranching programmes in operation in Scotland, protected by Several Orders. Lobsters which are of more interest to those proposing reefs are, as yet, not covered by a Several Order. This issue has been raised in the House of Commons. In 1992 David Curry MP expressed the intention of MAFF to include lobsters in the list of species already covered by existing legislation. However, this was to occur 'when the opportunity arises' (Hansard, 11 June 1992).

Unless an artificial reef is protected by a Several Order it will remain an open fishery. It is unlikely that any investment in stock enhancement will occur whilst in this state although small, geographically isolated communities may be able to self-police a stock enhancement programme for the benefit of the whole community. Some aspects of reef management will not need the protection of a Several Order. Reefs built to enhance sport diving will obviously not require fisheries protection, while reefs built to enhance local sport angling opportunities could probably rely on self-policing and are less liable to over-exploitation.

(2.4 and 2.5) Section Summary: Legal aspects of reef deployment and Property rights

The deployment of artificial reefs is considered dumping under international law. Much of the legislation governing reef deployment is determined by the European Union (EU). In many of the relevant conventions governing the protection of the marine environment artificial reefs are not specifically mentioned. This has resulted in confusion and disagreement over interpretation of regulations and how they apply to reef development. This is particularly pertinent to reef material which contains very small quantities of implicitly banned substances yet whose deployment can be shown to be non-detrimental. The broad acceptance of the precautionary principal by other EU states means that it may become increasingly difficult to deploy reefs that contain even trace concentrations of banned substances (such as metals found in coal ash)

Fisheries ownership rights are also included in international regulation. Under the adoption of 'mare libarum' *in 1609 fisheries have been afforded an open access status. This means that fish cannot be owned until they are caught. This has implications for reef development because it means that the reef developer cannot deny access rights to fisherment unless it is for a species covered under the Sea fisheries (Shellfish) Act (1967). This act may be widened in the future to cover species suitable for artificial reef based aquaculture. This will allow a reef operator to legally own stock on the seabed thus encouraging investment in this type of mariculture.*

CHAPTER 3. ARTIFICIAL REEFS ON THE WEST COAST OF SCOTLAND

This chapter puts the information given in chapter 2 into the context of an artificial reef development on the west coast of Scotland. It includes information gained from contacts with relevant legislative bodies, such as the Scottish Office and the Crown Estate Office, in addition to technical information from companies concerned primarily with the production of concrete using waste materials produced in abundance on the west coast. It concentrates on issues such as the potential for increasing sport diving and fishing in the area and the beneficial utilisation of waste products in reef construction.

SECTION 3.1 Legal and administrative issues relating to the west coast

There are a number of legal factors affecting the deployment of an artificial reef on the west coast of Scotland (and Scotland as a whole). The main planning authority is the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) (see subsection 3.1.1) while a lease is required from the Crown Estate Office to use specified areas of seabed (see subsection 3.1.2). Reaching the stage of making an application to SOAEFD for a licence and the Crown Estate Office for a lease is lengthy and requires very detailed, careful planning and consultation.

Subsection 3.1.1 Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD - 'The Scottish Office')

The Scottish Office is responsible, under the adoption of UNCLOS III (see subsection 2.4.1.1), to licence dumping at sea. This is done under the provisions of the Food and Environment Protection Act (1985) (FEPA) (as amended by the Environmental Protection Act (1990)). There are three types of FEPA licence to cover differing waste materials. These are:-

- Licence for Marine construction works/ land reclamation/ beach replenishment
- Licence to deposit solid waste (eg dredged material, fly ash, colliery waste etc.) in the sea
- Licence for the sea disposal of bulky wastes (eg redundant oil platforms)

It is the policy of the Scottish Office not to licence reef construction using opportunistic waste materials such as compressed cars or tyres. This is not the case for reefs constructed using natural aggregate waste material especially when it can be shown that waste disposal is not the sole reason for reef construction. The utilisation of large steel structures such as redundant oil production platform components is also not ruled out by the licencing authority. However, to obtain a licence for the disposal of such elements would require a considerable amount of time and effort to show that the sea disposal option was the 'best practical environmental option' (BPEO).

Whilst massive steel structures such as rigs and redundant ships can last many years in the marine environment they will eventually decay. The Scottish Office wish to retain the right to require the reef owner to remove the reef should it be corroded to such an extent that it no longer serves its initial purpose, causes some unforeseen problem or if there is a change in circumstances (including a change in the receiving environment, a change in knowledge regarding the reef or a breach of contract). This requirement serves to protect the marine environment and other users of the sea from any eventuality involving the reef (by requiring reef owner liability). The removal of a semi-corroded massive steel structure could be prohibitively expensive.

The licence cost is proportional to the time taken to process the application. This increases considerably when a BPEO review is a requirement. Generally the marine construction works licence is the cheapest while the sea disposal of bulky wastes is the most expensive to obtain.

The BPEO review is required for a licence to deposit solid waste and a licence for

the sea disposal of bulky wastes. This demanding requirement obliges companies to consider alternatives. However, excessive cost is still considered a viable reason to reject alternatives and continue with the application for a licence to dump at sea.

The use of redundant fishing vessels in reef construction and the legal issues associated with this are discussed in subsection 3.3.3.

A recreational reef constructed from, for example, large concrete culverts would require a marine construction licence. No BPEO is required for this type of licence and it is relatively easy to obtain. Further development of the reef could occur if the initial development was shown to be successful.

The Scottish Office would oblige any applicant for a reef licence to consult the Department of Transport to enable that office to apply any regulations applicable to the reef development (normally this will involve shipping regulations).

Subsection 3.1.2 The Crown Estate Office

The vast majority of the seafloor extending to the 12 mile territorial limit is under the jurisdiction of the Crown and administered by the Crown Estate Office (whose policies are determined by the Crown Estate Act, 1961). The establishment of any sort of structure on the seafloor within the territorial limits requires a lease from them (assuming it is within their jurisdiction). This includes moorings, salmon cages, mussel farms and artificial reefs.

The stance taken by the Crown Estate Office in granting a lease for the use of sea bed to site an artificial reef is broadly similar to that of the Scottish Office. The Crown Estate Office have stated that they would require proof of ownership and of long term liability and responsibility. These conditions are already a requirement of a FEPA licence issued by the Scottish Office. The Crown Estate Office demand that any reef developer take full responsibility for any eventuality that occurs as a direct result of the construction of the reef, for example any shipping or sport diving incidents.

In terms of planning, the Crown Estate Office would not be involved except where there was a potential conflict of interest between the reef owner and another user of the subshore Crown Estate. The reef developer is likely to require of the Crown Estate Office that they do not allow another development in proximity to the reef which would be deleterious to that reef.

Subsection 3.1.3 Consultation procedure

A broad scope consultation exercise is one of the requirements stipulated by both the Scottish Office and the Crown Estate Office. The aim of such an exercise is to ensure that any public body, non-governmental organisation, ecological/ ethical interest group or private individual can make a representation regarding the site and nature of any artificial reef development. Any concerns raised are considered by the Scottish Office in granting a licence. A licence will not be granted if the Scottish Office believes that the reef would realistically harm, for example, a fisherman's livelihood. The Crown Estate Office requires a consultation procedure to ensure that there is negligible chance of user conflict occurring as a result of the reef development, especially conflict between users of the marine estate leased from the Crown.

Subsection 3.1.4 Scottish Natural Heritage (SNH)

There is no coherent policy from the SNH concerning artificial reef development. They would consider each project on it's individual merits. Interest in the scheme would depend on the proposed site and any natural history value. This could include rare species protection. The SNH are not against artificial reef development on principal. However, they consider an artificial reef generally to have less natural history value than a naturally occurring reef and do not consider that artificial reefs enhance opportunities for natural heritage.

An artificial reef development may have an educational role with the purpose of the reef being explained on the shore with further explanations of marine life provided underwater in the case of a reef designed for sport divers. Public education is an unquantifiable though real benefit. As public education is part of the remit of the SNH such a reef may gain their active support.

Subsection 3.1.5 Non-governmental organisations

This includes environmental concern groups such as the Marine Conservation Society, the Royal Society for the Protection of Birds and any other identified during the consultation process (see subsection 3.1.3). The position of the Marine Conservation Society is non-committal, whilst they oppose the sea dumping of redundant oil platforms they would not believe it necessary to become involved in opposing the type of development that would encourage sport diving. They have no policy stating opposition to lobster stock enhancement through artificial reef development although they have expressed concerns over the use of pulverised fuel ash (see subsection 3.3.2) as a construction material.

Subsection 3.1.6 Fishing interests

The fishing lobby is a powerful one in the UK as a whole and this includes Scotland. The view taken by the Scottish Office is that the best site for a proposed reef development would have virtually no fishing activity.

Any reef development should only occur with the good will of the fishermen. In this way barriers to gaining permission are less likely to occur and the potential for future conflict is reduced. Given that a recreational reef is likely to be close to the shore it is unlikely that bottom trawling will be affected. A reef development is likely to enhance the lobster and crab populations in the area and therefore should be welcomed by trap fishermen.

Permission to construct an artificial reef for use by sports divers has been considered on the west coast of Scotland in the past. One of the stated purposes of the reef was to protect the sea floor from trawling. As there is no legal mandate for this the Scottish Office were obliged to reject the proposal as a result of the concerns of the fishermen.

(3.1) Section Summary: Legal and administrative issues relating to the West Coast

Any artificial reef development requires a licence under the Food and Environment Protection Act (FEPA)(1985). This implements international obligations resulting from the coming into force of the United Nations Convention on the Law of the Sea (1982) of which the UK is a signatory. The type of licence required under FEPA depends on the reef construction material. Concrete blocks would require a 'marine construction works' licence whilst the utilisation of redundant oil rigs would require a 'disposal of bulky waste licence'. The complexity of the licence application depends on the proposed material; a marine construction works licence is by far the most simple to obtain. Part of the licencing requirement is a 'consultation exercise' where any proposed reef development is publicised. This allows representation from any interested party (commonly environmental interest groups and fishermen) and these representations are considered by the Scottish Office when deciding on the licence application. Justified complaints, especially from fishermen, would normally prevent the granting of a licence. The area of seabed destined for reef deployment would require a lease from the Crown Estate Office. They have expressed concerns over long term commitment and would require some proof of this prior to leasing an area of seabed.

SECTION 3.2 Potential benefits to the Argyll and Lochaber economies

An artificial reef development could be self-funding with revenue being derived from various sources. Increased tourism would benefit the whole of the west coast area, lobsters produced from a ranching operation would support fisherman and associated trades. The use of a quarrying waste product (with or without ash from power stations) in a pro-active and positive way may improve public perception of the quarrying business and provide an environmentally preferable and cost effective method of by-product utilisation. These aspects are discussed below.

Subsection 3.2.1 Recreational diving

The west coast of Scotland is extensively used for water sports recreation. This includes sport diving where North Argyll and areas of Lochaber (e.g. Lochaline) are active centres with several diving schools and dive suppliers. Divers come to these areas because of the clear water, exciting wrecks, abundant marine life, established diving facilities and above water scenery. Whilst having numerous advantages the both areas have few safe, relatively shallow yet interesting dive sites. This means that these areas cannot provide adequately for newly qualified sports divers. The tragedy that occurred on one of the few relatively shallow wrecks (The 'Breda' where 2 divers were trapped and drowned) in May 1995, indicates the dangers faced by all divers, a danger exacerbated by inexperience. Local opinion from dive schools indicate the need for interesting protected shallow water dive sites. Ideally this would be close to a diving school and would give inexperienced divers a safe, exciting introduction to sport diving which would attract them back to these areas.

3.2.1.1 Economics. The lack of research into the numbers of divers visiting these areas means that predicting the increase in divers coming in as a result of a reef development is difficult. Artificial reefs in other countries have been very successful with, for example, a 19 wreck reef near the Bruce Peninsular, Ontario, Canada attracting thousands of divers every year with subsequent massive benefits to the local economy. Charter boat owners, diving equipment suppliers, hoteliers, guest houses, public houses and restaurants all benefit from this type of increased tourism.

No formal analysis has been conducted on the amount that divers spend whilst on a diving holiday. Data has been gathered on the more generic 'water sports' area of tourism by the Scottish Tourist Board. This indicates that £6M per annum is spent on water sports in the Highland region and that most people involved in water sports are less than 46 years old, are in ABC1 socio-economic groups with 90% of water sports holidays occurring between April and September.

The results from a limited initial survey of opinion has shown wide variations in predicted amounts spent by divers whilst on diving holidays and the number of divers coming to the North Argyll area. Data on the amount spent by divers are shown in table 2.

Table 2 Estimates of diver spending and length of stay

Information Source	**Average spend per day**	**Average stay**	**Total**
Scottish Tourist Board	£35	7 nights	£240
PADI feasibility study, Canada	£35-50	4-5 nights	£140-£250[1]
ICIT, Orkney[2]	£100-£120	6 nights	£600-£720
Oban Coastguard, diving liaison officer	£40	5 nights	£200[3]

1 - excludes personal spending, converted from Canadian dollars

2 - The 'International Centre for Island Technology' (ICIT) conduct research into diving because it is an important part of tourism in the Orkney Isles.

3 - This value doesn't include the cost of charter boats (amounts to £30 per day per diver)

A sport diving reef would be situated in a sheltered location allowing divers to visit during the winter period (when good water clarity is an attraction). This would increase trade when it is particularly valuable to those whose livelihoods are dependent on tourism. Estimates for the increase in diving tourism that could be

expected as a result of an artificial reef vary. The Oban Coastguard estimate a 20% increase in diver numbers. If the attraction was made sufficiently novel and interesting and was well publicised then diver numbers could increase above this level.

3.2.1.2 Site development. The initial recreational diving reef is likely to be small. The reef could have open access, at least initially. If it proves to be a success and is well used and liked by visiting divers then the range of subsea attractions could be increased with the extension of the reef. This could include the addition of wrecks (redundant fishing vessels (see subsection 3.3.3) or decommissioned military equipment (see subsection 3.3.4)) although there is doubt over the licencing of such materials. The further design of the reef would be controlled, in part, by the wishes of recreational divers. It is likely to be used to a much greater extent if easy shore access is provided.

The extra parking required to accommodate a large number of divers visiting an artificial reef should be considered in costing the development. However, a well constructed car park could allow the collection of a fee for parking (and by implication diving). Initial car park building and maintenance costs should be included when considering the viability of a reef development. If the car park was an extension of an existing car park utilised for another attraction then it is likely that some of the divers (or non-diving members of the family) would visit that attraction. In this way an extra benefit would result, and the cost of the extra parking facilities be mitigated.

3.2.1.3 Commitment. A reef development would require long-term financial commitment from the reef owner/ operator. The degree to which the reef would require maintenance will, in part, be a function of the material from which it is built. Larger structures such as redundant fishing vessels would last many years underwater but eventually would need attention or reconfiguration to ensure they remained safe for divers. This cost has to be considered by the proponents of the artificial reef as long term commitment and responsibility is one of the requirements of the Scottish Office in granting a FEPA licence.

3.2.1.3 Negative aspects. Negative aspects of increased diver tourism would be a symptom of the success of the project. Increased traffic could be expected and the impact on the marine environment may include the removal of certain species (scallops and lobsters for example). However, the concentration of diver activity may draw divers away from untouched areas and thereby help to preserve them. Over-use of artificial reefs is sometimes a problem in the United States where diver numbers are much higher and where the solution has often been to build more reefs.

If the artificial reef is not used by divers then it will remain as a hindrance to other marine activities and the owners may be required, under the terms of the Crown Estate Office's lease and the Scottish Office licence, to remove the structure. This should not occur if the concept of the reef is considered properly and publicity/ advertising levels maintained.

Subsection 3.2.2 Sport fishing

In many areas of the world the importance of sport fishing as a recreational activity, source of local employment, income and, if properly managed an aid to scientific research has been understood and accepted. Most sport fisheries, now worth millions of pounds, were started by small groups of enthusiasts who identified the potential in their locality. In the UK the sport fishing industry is concentrated around the southern part of England where anglers target blue shark and conger eel. In that part of the UK there are dozens of boats (up to 30 per port) catering for all types of fishermen. Sport fishing is weather dependent but otherwise occurs all year. This means that it can bring welcome business to areas dependent on tourism especially during the winter months.

3.2.2.1 Sport fishing on the west coast. The sport fishing industry is very underdeveloped on the west coast of Scotland despite the potential for this industry. The following information is gathered from communication with the 'Big Game Club of Scotland' who operate their boat from the Oban area. This club has over 15 years of experience in game fishing and have invested considerable sums of money in the sport. The range of sport fish available for fishermen on the west

coast of Scotland is considerable and greater than that of the west coast of England. It includes sharks (e.g . shortfin, mako, blue, thresher) and tuna (bluefin, skipjack and albacore) among others. The west coast of Scotland is the only part of the UK where such fish are to be found. This is why the 'Big Game Club of Scotland' (BGCS) based their purpose built boat ('Magnum') in this area. The research and experience of the sport fishermen in this club identified the west coast of Scotland as having considerable potential for the sport hence their investment (£165,000) in the 'Magnum'.

3.2.2.2 The requirement and role of artificial reefs in enhancing sport fishing. The sport fish which visit the west coast of Scotland are generally in search of food. Some follow well defined migrations which occur during the movement of warm water northwards during the summer months. Bait fish are attracted to reefs of which there are few close to ports such as Oban. This means that to access the sport fishery vessels are required to go offshore. The licence required by the Department of Transport for offshore sport fishing demands a high level of capital investment in safety equipment and crew training. This forces the cost of fishing up and restricts the numbers of boats that can access the reefs. This is one of the reasons why recreational fishing is currently under-developed in the North Argyll and Lochaber areas.

An ideal reef to enhance the sport fishery would be situated in between 40 - 60 metres of water, near to headlands and tide races but just out with the full force of the tide. In addition such a reef would ideally be near to a body of deeper water. Such a reef would attract shoals of bait fish by offering shelter from current, predators and by providing food. This in turn attracts the sport fish. Sport fisherman are likely to fish for both the bait and sport fish (depending on the preference of the fisherman). Areas suitable for further investigation have been identified around Mull and the Ardnamurchan peninsular.

3.2.2.3 Potential conflicts and co-operation. The ideal situation for a sport fishing reef is near the shore where there is generally little trawling activity. In such areas a majority of commercial fishermen are creel fishermen who are likely to

welcome an artificial reef as it would enhance the grounds for lobsters and crabs. Should the development of a sport fishing reef be combined with that of a lobster ranching programme then the two activities would enhance each other. The sport fishermen would monitor the reef and would be able to report poaching or other suspicious activities. This activity could occur with no detriment to other forms of fishing and therefore the scope for conflict within the fishing community is reduced.

3.2.2.4 Economic benefit from sport fishing. Big game sport fishing (such as that offered by the 'Magnum') attracts people whose sole interest in coming to the area is to fish. Groups of fishermen generally come from sport fishing clubs. Some stay in bed and breakfast accommodation and fish on a day-trip basis while others stay on the boat for the duration of their fishing trip. Hiring offshore charter boats such as the 'Magnum' costs around £300 per day. A majority of the trips undertaken by the 'Magnum' are 1-2 day-trips with fishermen from Scotland. Longer trips are generally booked by English fishermen and attracting wealthy anglers from all over the Europe is certainly possible.

An artificial reef would serve to 'hold' both bait fish and sport fish during the winter months thereby extending the sport fishing season. Currently weather restricts the operation of sport fishing vessels with anything over a force four preventing fishing on exposed parts of the coast. This restricts the use of the fishery and could lead to the disillusionment of fishermen and a lack of return trade. One of the reasons an artificial reef would promote the sport fishing industry is through the provision of a more weather independent fishing site.

Research into areas with sport fishing potential has already been conducted by 'The Big Game Club of Scotland'. It resulted in the initiation of shark fishing in Scrabster during 1989 - 1990 where the worlds largest porbeagle shark was caught (well publicised records like these attract fishermen from all over the world). There are now up to five charter fishing boats operating in the Scrabster area during the winter months. This has been to the enormous benefit of local hotels and B & B establishments who enjoy extended winter business.

Maintenance of charter boats is likely to be done locally, a boat such as the 'Magnum' costs about £6000 per annum to maintain. In this way the revenue gained from an enhanced game fishery is likely to stay in the local area. The charter boat 'Magnum' has 124 bookings for 1997 already (worth over £58,000), the 'Lady Jane' (another big game sport fishing boat) has roughly the same and also charges £300 per day. By extrapolating the numbers of sport fishing charter boats in just Oban to 15, operating for 200 days in the year the revenue could approach £1M per annum. Sport fishing could be extended to ports the length of the west coast of Scotland and help areas depressed by the imposition of new fishing quotas.

3.2.2.5 Sport fishing and research. Well managed sport fishing contributes considerably to research into the behaviour, especially migrations, of sport fish such as sharks and rays. This is done by the tagging and release of most of the catch from sport fishing. The crew of the 'Magnum' are charged with the tagging and recording of details of sport fish by the Museum of Glasgow and by the Predator Research Group in the US Department of Marine Research to study trans-Atlantic migration of sharks.

Subsection 3.2.3 Fishery enhancement

Artificial reefs were originally used for fishery enhancement. There are many examples of the use of artificial reefs to increase fish catches. Debate over whether an artificial reef increases the fishery through a genuine increase in productivity or whether the reef merely attracts fish from other (natural) reefs (the 'production versus aggregation' issue) remains unresolved. However, there is certainly potential for lobster ranching on the west coast of Scotland and research into using reefs to ranch other species is ongoing.

3.2.3.1 Lobster ranching. In the UK the main species of interest to artificial reef ranching is the lobster. Work is continuing at the Shellfish Research Laboratory, Conwy, North Wales to design reef blocks or arrangements of reef blocks which create the best lobster habitat. A cost benefit analysis done on the ranching of lobsters on an artificial reef concluded that such an operation is likely to be viable. Important factors determining the viability of such a venture include the

productivity of the area (which is dependent on water temperature and food availability), the price of the product and the costs of the reef. Careful site selection would indicate areas where lobsters growth is likely to be optimal and the costs of the reef should be minimal if waste aggregates are used in its manufacture. Furthermore, ongoing research will indicate the optimal reef design in terms of suitability for lobsters which should make such a programme very profitable. See Whitmarsh (1994) for the cost benefit analysis of lobster ranching.

Contacts with experts has indicated that an ideal sport fishing reef would also be ideal for lobster ranching (in terms of depth, exposure to currents etc). It is probable that any lobster ranching programme could be coupled with sport fishing. This would increase the economic viability of the operation.

Sea floor type is a very important factor in determining the site for lobster ranching. Juvenile lobsters live in burrows in soft sediment prior to moving into the sort of rock crevices that would be supplied by the artificial reef. The sediment needs to be of the correct type to enable burrow construction by the juveniles. Ranched lobsters with a good food supply are less likely to 'wander' because of the reduced foraging requirement. This also minimises predation on the lobster by limiting the time spent outside the protection of the burrow or crevice. An 'immature' reef is unlikely to provide adequate food, it will need to be in place for several years before a biological community can develop to sustain lobsters in economically viable densities. Growth of fouling organisms and the productivity of the reef will depend on its location in terms of exposure to water currents and light (which will be proportional to water depth and clarity). Research into what generates the best environment for lobsters is ongoing and indicates that it may be possible to design a reef that maximises the numbers of the preferred food items for lobsters.

Lobster populations have been monitored on the Torness artificial reef (see subsection 2.2.2). There was an indication that the reef had an enhancing effect on the lobster catch. From this work it was concluded that the reef may well provide the refuges for the juvenile lobster and enhance the sustainability of the fishery by

improving the survivorship of juveniles.

Property rights are a major issue when considering the value of lobsters on an artificial reef (see section 2.5). At present there is no protection available under UK law for ranched lobsters. A change is required in the Sea Fisheries (Shellfish) Act (1967) to include lobsters before commercial investment in ranching is likely to begin.

3.2.3.2 Other species. The range of species that could be ranched using artificial reefs as a substratum is large and many species other than lobsters have been investigated in the UK. Studies into cod ranching and the ranching of spiny lobsters (which have several advantages over lobsters) have been conducted. Most are at an early stage but the development of a reef programme in this area is likely to attract further research into reef ranching of commercially important species. The development of an artificial reef programme will attract interest from the UK and Europe into researching the feasibility of ranching species other than the lobster. A reef development could be the basis for an application for a Several Fishery Order thus giving ownership rights to stock.

Subsection 3.2.4 Scientific Research

Reefs enable scientists to control certain elements of the environment and thus it makes them ideal sites for scientific research. Contacts with experts in the field of artificial reef development have indicated a need to progress from desk studies to reef deployment. As reefs become accepted as a means of sustainably managing and enhancing fisheries interest in them will rapidly increase. It is in the interests of the Argyll area to promote research into reef development as it is likely to increase the amount of both central Government and European funding. In addition to all the other benefits the development of an artificial reef programme will provide jobs for scientists and make the Argyll and Lochaber areas centres for reef research.

SECTION 3.3 Construction materials

A enormous variety of materials have been used in the construction of artificial reefs worldwide. Not all have been successful. During this study a number of potential reef construction materials specific to the North Argyll and Lochaber areas but applicable to the whole of the UK have been identified. Current disposal methods for bulk aggregate waste are very expensive. The development of an artificial reef programme could be of considerable benefit to companies producing waste aggregates by providing a safe method of utilising what once was a waste material. These are discussed below.

Subsection 3.3.1 Waste aggregates from quarrying operations.

Quarrying operations produce a variety of aggregate waste products. These can range from boulders and rocks contained in overlying soil and subsoil to a very fine material produced as a result of aggregate washing. During some quarrying operations aggregate is produced by crushing rocks. The aggregate thus produced is separated by a series of sieves. Any aggregate less than 3 mm is termed 'dust' and has a limited but definite value. Many types of rock degrade over time generating an assortment of products which depend on the nature of the parent rock. Granite, for example, contains various types of the mineral feldspar which degrades to a very fine clay. If present this clay devalues the aggregate so it is washed. The 'washings' have no value and pose an expensive disposal problem. 'Washings' are produced in large quantities (hundreds of thousands of tons) on the west coast of Scotland and are a potential aggregate source for reef block construction. The size of the particles in washings ranges from 10 - 63μm (several thousand times finer than 'dust').

The use of washings in concrete manufacture and the placement of such concrete on the sea floor present some particular problems. These include:-

- As a result of being very fine the dust/cement mixture requires a considerable volume of water to make it workable.
- The large volume of water means that the concrete is quite weak and it is liable to shrink in air and expand in seawater.

- If produced in large blocks (5 - 10 tons) then it will require an internal steel wire frame to support it during handling operations (handling includes the loading into a boat and sea deployment).
- The nature of the washings means that it is difficult to adequately disperse the cement. Mixing this sort of material requires specialist plant (which is readily available but may be expensive).
- A higher proportion of cement may be required because the high surface area of washings.
- In order to resist chloride present in sea water the cement will need to contain a high proportion of blast furnace slag. This increases the setting time from 7 days to 1 month but ultimately gives a stronger block.

Despite the above mentioned disadvantages the requirements of artificial reef blocks are not very demanding meaning that compromise is possible. Artificial reef blocks are not required to be very strong (as they are not going to be load bearing). Shrinkage and cracking should not be a problem in standard block sizes (20 cm x 20 cm x 40 cm). The curing time required by the incorporation of blast furnace slag cement means that the blocks will require some storage (about a month) but will develop into a stronger block for less expense (blast furnace slag cement is less expensive than Ordinary Portland Cement).

Whilst the blocks are not required to bear loads they do need to be strong enough to withstand the marine environment and, for example, not break up during winter storms. The relative proportions of the constituents will, in part, determine the strength of the concrete. The inclusion of some dust (which is coarser) into the mixture may allow a reduction in the required cement content and make the blocks stronger. The reduced requirement for cement will reduce the cost of the block, especially if the blocks are made on site where excess dust may be present and have no value. Further research needs to be conducted to establish the best mixture of washings and cement, the optimum ratio of blast furnace slag cement/ordinary Portland cement in the final mix and whether the cost of the mix can be reduced by the inclusion of 'dust', other coarser aggregates or ash (see next section).

Subsection 3.3.2 Coal ash

Vast quantities of ash is produced from coal-fired electricity power stations. PowerGen Plc alone produce 2.5 million tonnes per annum. In addition to this Scottish Power and Alcan Smelting and Power UK also produce ash. All three power generators have expressed an interest in this feasibility study. There are different grades of ash each having different properties and values. Furnace bottom ash (FBA) is a relatively coarse aggregate which normally poses a disposal problem. Pulverised fuel ash (PFA) is a much finer product, some grades of which can be used in the manufacture of cement additives. These grades are sold and therefore do not pose a disposal problem. Some grades of PFA are not suitable for use in cement additives but can be used as an aggregate (to be mixed with cement) for the production of 'breeze' blocks for the construction industry or for major civil engineering projects such as road building where it is used for infilling. Despite numerous uses ash is overproduced, about half of the pulverised fuel ash is used, the other half requires disposal. Coal ash (unlike municiple incinerator ash) is regarded by the Health and Safety Executive as a non-toxic inert product. Whilst it does contain trace amounts of heavy metals these are chemically bound within the silica matrix of the ash.

PFA and FBA are used in artificial reef block construction all over the world. One of the first experimental reefs in the UK (Poole Bay, England) was constructed using PFA (mixed with cement, ballast and flue gas desulphuration gypsum). The blocks have been shown to be durable and to suffer negligible leaching of metals with no subsequent bioaccumulation in colonising organisms over the eight years the blocks have been in the sea. (Bioaccumulation is the process where organisms accumulate and concentrate toxins present in their environment, this accumulative effect can result in toxin concentrations in the organism that are many times greater than that found in the environment).

There are no coal powered stations on the west coast of Scotland at the moment, the nearest such station being Longannet Power Station (on the Firth of Forth), operated by Scottish Power who have shown particular interest in this research. Land filling of ash currently costs £2 per tonne and it is predicted that this will

increase. This together with a forecasted increase in power generation using coal has focused attention on the need to use ash in a pro-active manner.

Consultation with experts (Dhir, pers.comm,(1996)) in the field of ash utilisation has indicated that some of the waste ash products (ash products currently requiring expensive land fill) could be used to strengthen a block made from quarry washings. It might therefore, be possible to combine these two products to form a robust block suitable for reef construction very cost effectively.

Subsection 3.3.3 Redundant fishing vessels

Decommissioned fishing vessels that have been cleaned (ie all oil, grease and active antifouling paint removed) would make an ideal sport diving reef. However, under agreements made by the UK government at the last North Sea Conference (see part 2.4.1.4) all sea disposal of decommissioned fishing vessels is to be banned in 1998. Whilst the Scottish Office have acknowledged the argument that using a redundant fishing vessel for a new role as an artificial reef could be considered to be something other than dumping, they are actively discouraging this use of such vessels. It therefore seems unlikely that this source of material for artificial reef construction will be licensable. Any similar material would require a 'licence to dump bulky wastes'. This is relatively difficult and expensive to obtain.

Subsection 3.3.4 Other redundant structures

This would include decommissioned ex-military equipment such as tanks and aircraft. This avenue has not be explored under this feasibility study. In the US decommissioned battle tanks are being used in Alabama to construct artificial reefs. The thick steel armour on tanks is expected to survive 50 -100 years in seawater. The US military are hoping to sink around 1000 tanks per year for artificial reef development.

(3.2 & 3.3.) Section Summary: Potential benefits to the Argyll and Lochaber economies and construction materials.

Several potential uses for artificial reefs have been identified in the North Argyll and Lochaber areas. These include sport diving, recreational fishing and lobster ranching. Sport fishing is the basis for many of the artificial reef programmes all over the world. Diving tourism is valuable and can be promoted using artificial reef technology. Lobster ranching has shown potential and it may be possible to combine a lobster ranching and sport fishing reef based on concrete blocks (see section 3.3.). Research into techniques for ranching lobsters is ongoing and quite well advanced, however, the lack of legal protection for ranched lobsters is currently restricting the development of the industry. There is likely to be potential for the ranching of other commercially important species on an artificial reef although this is currently under-researched. The establishment of an artificial reef in the North Argyll or Lochaber area is likely to result in major grants from Europe and from central Government for further research.

Whilst a large number of materials have been used across the globe in reef construction many are not applicable to the Scottish coast. This is mainly because of licencing restrictions and availability. Compressed cars for example, have been used in many areas but it would be impossible to get a licence to use this type of material in reef construction in Scotland. In the North Argyll and Lochaber areas two potential sources of material for use in reef construction have been identified. The first is 'washings' produced as a quarry by-product. This fine material is produced in large quantities near to potential sites for reef deployment. The second material identified is ash from coal fired power stations. Producing a block from quarry waste alone has numerous technical difficulties relating to the softness of the resultant concrete. Certain types of ash may, if incorporated with the quarry waste, result in a much stronger block and enable the minimisation of expensive components such as cement. The technical challenges associated with block manufacture using these materials are a major research requirement.

SECTION 3.4 Site selection criteria

Site selection is critical for the success of the reef in performing the desired task.

Subsection 3.4.1 Design criteria

When considering possible sites numerous factors should be taken into account. The optimum site for the reef will depend on the function for which it is required. A range of factors that should be considered when designing an artificial reef are shown in Table 3. As mentioned in part 3.2.2.3 it is unlikely that a single reef could serve sport fishermen, lobster ranchers and recreational divers. The greatest overlap exists for sport fishermen and lobster ranching. A reef could be designed to serve both these needs, such a reef would not attract divers because it is likely that to be too deep, uninteresting and remote.

Subsection 3.4.2 Techniques in site selection

Geographical information systems (GIS) incorporating exclusion mapping are techniques well suited for reef site selection. These systems enable the user to define areas unsuitable for reef deployment. In this way, for example, areas of seabed less than 40 and more than 60 metres deep can be excluded. On this exclusion map the user can superimpose another such as one excluding all areas more that five miles from the nearest port. In this way the GIS can eliminate unfavourable areas for whatever reason leaving the user with suitable areas. These are then generally examined for suitability on criteria not applicable to the GIS which includes the presence of other users in the area and area specific licencing restrictions.

Table 3 Site selection criteria for artificial reef construction: relative importance of criteria for different uses

FUNCTION	Recreational diving reef	Sport fishing reef	Lobster ranching reef
Site characteristics			
Bottom type	Sandy bottom type would be preferable to allow easy diver training and to maintain high visibility	Bottom type will be dictated by the current regime in which the reef is located	It is essential to locate the correct sediment type to allow juvenile lobsters to burrow and feed adequately
Stable surface	A flat or nearly flat bottom is preferred to help prevent the reef moving and to facilitate diver training.	A stable reef is likely to be more productive than one which can move.	Area should be stable and not liable to massive currents which could smother the reef with sediment
Depth	**Very important, an interesting reef could rise from a max. of 20m to break the surface. This would encourage a variety of life and enhance photographic opportunities**	A depth range of 40 - 60 metres would be ideal for both sport fishing and lobster ranching. Because wave energy would be much reduced at this depth the reef would be less liable to move or be eroded.	
Proximity to shore	**Very important, shore access would improve the popularity of the site and allow its use when the weather prevented boat access.**	Important: Proximity to shore would increase the profitability of both ranching and sport fishing by reducing the time and fuel spent travelling. A close reef would also allow access by boats without the offshore charter boats licence which currently restricts the development of sport fishing in the Argyll area.	
Location (in relation to other boat traffic)	Any non-diving boat traffic is likely to cause a considerable danger	Important, the reef should be out with traffic routes	No relevance so long as the reef is in deep enough water. Creel buoys may interfere with traffic.
Presence of fishing activity	Both sport and commercial fishing activity could endanger divers	**Very important, commercial fishing would endanger the reef. Such factors are a priority in site selection.**	Fishing activity would be tightly regulated. Fin fishing would not affect the reef and may be an added bonus to local communities
Weather Exposure	Maximise usage (and profitability) by minimising exposure. A low exposure site would reduce damage to the reef.		A low exposure site would allow regular harvesting and reduce storm damage.

Reef structure characteristics			
Durability	Important as increased durability will reduce maintenance effort	The life expectancy of the reef will determine both the economic and licencing viability of the reef. The blocks must survive long enough to allow the reef to pay for itself	
Presence of toxic materials	All potentially toxic materials including grease and oils would have to be removed from the reef components	Licencing would require proof that pollutants would not escape from the reef block matrix. Biologically available pollutants would harm the lobster and it's habitat and reduce the saleability of the lobster	
Movable objects (such as doors or hatches)	All movable objects such as hatches and doors should be welded open or shut to prevent accidents	Not relevant	
Interest	**Essential, the more interesting and novel the site the more divers it will attract**	An interesting reef would be a disadvantage in that it may attract divers which could result in poaching and would interfere with other users of the reef	
Site compatibility/ user conflicts			
Ongoing assessment of problems associated with the reef	**Must maintain good relations with people living and working near the reef and try to involve them in a positive way. Once established and having gone through the licencing procedure there should be little scope for user conflict.**		
Information displays	Useful; maps and diagrams will enhance the use of the reef and will encourage care from the divers	Publicity for the reef should be maximised.	Publicity over the lobster reef should be minimal once established.
Site safety and concern for liability			
Emergency contingency planning	**Essential and could include the provision of a pay phone nearby**	Unimportant	
Buoyage	Useful to direct divers to different parts of the reef. Lines may also lead from the shore to the reef	Unimportant	Creel fishermen will buoy the lobster creels in the standard manner
Provision of warden/ supervisor	Possible, especially during the peak season. The warden could be in charge of the car park and charges	Not relevant, the reef needs to be self-policing	
Statement of liability	If deemed necessary by legal experts	Unnecessary	
Risk management assessment	Yes, the risk from diving on the reef should be assessed (it will be designed to be safer than alternative sites)	Unnecessary	

Site and reef management		
Clear ownership and responsibility	Liability for accidents must be placed on the individual divers or the schools responsible for the divers	Liability for the reef is a licence requirement. Ongoing monitoring would require funding.
Reef inspection	Inspection will be part of the safety audit and may result in reef reconfiguration and maintenance	A considerable amount of scientific data will be gathered concerning the performance of the reef (this would possibly include population assessments of lobsters and the continued tagging of specimen fish by the sport fishermen).
Access facilities/ on shore diving facilities	**Of prime importance, car access in particular must be very convenient. Shore diving facilities could include compressed air, toilets, showers. The sea must be within easy walking distance, with easy and safe entry points at all states of the tide.**	All facilities are likely to be provided by the boat and boatman.

(3.4) Section Summary: Site selection

Reef design and materials selection will be determined by the required function of the reef. It is unlikely that a single reef could be developed to satisfy the requirements of sport divers, sport fishermen and lobster ranching. The greatest overlap in criteria would appear to come from a combined sport fishing and lobster ranching reef. Such a reef is unlikely to attract recreational divers because it would be too deep, uninteresting and remote. Methods of site selection include the use of geographical information systems and techniques such as exclusion mapping. This process eliminates areas with unsuitable attributes relating to depth, substrate type, current / weather exposure and proximity to port. Areas that are left after this exclusion process are then considered ideal candidates for further research into their suitability.

CHAPTER 4. CONCLUSIONS

This chapter outlines the broad conclusions of the feasibility study particularly issues relevant to Scotland and makes suggestions as to future research priorities if an artificial reef programme proceeds.

SECTION 4.1 Feasibility study findings

Artificial reefs are rare in the UK, only coastal protection reefs have been used on a full scale whilst others have been experimental both in purpose and scale. Permission to deploy an artificial reef can be difficult to gain and depends on a variety of factors including site and materials selection. The licence required is given under the 'Food and Environment Protection Act (1985)' (FEPA), an act passed after the signing and coming into force of the United Nations Convention on the Law of the Sea (1982) (UNCLOS III). It is granted by the Scottish Office Agriculture, Environment and Fisheries Department in Scotland.

The deployment of an artificial reef manufactured from inert waste aggregates is viewed favourably by the Scottish Office and would require a 'marine construction works licence'. The 'marine construction works licence' has no 'best practicable environmental option' (BPEO) requirement making it cheaper to obtain.
Prior to the granting of a licence from the Scottish Office the applicants would have to satisfy a number of requirements. These would include an assessment of the impact of the reef material on the marine environment. It would need to be shown that the proposed construction material would have no adverse effects on marine environment or the livelihoods of other users of the sea. Any proposed reef would need to gain acceptance from non-governmental organisations such as environmental pressure groups and governmental organisations such as Scottish Natural Heritage. An application for the use of the sea floor would require the leasing of the proposed area from the Crown Estate Office who would need to be assured that the reef did not pose any risk to other users of the Crown Estate. Fishing interests would have to be addressed as would other interests identified by the consultation procedure which is part of the requirement for the licence as demanded by the Scottish Office. It is unlikely that a licence would be granted if any interests would genuinely suffer as a result of the reef. It is for this reason that

initial site selection has to find an area with few users and it is anticipated that this could be achieved without too much difficulty.

The use of waste material for reef construction has the advantage of reducing costs. The waste materials identified during this feasibility study that have the greatest potential for use in reef construction are 'washings' generated from the washing of aggregates and pulverised fuel ash (PFA) or other coal ash products generated from the burning of coal in power stations. PFA has been used in reefs all over the world including an experimental reef in Poole Bay, Dorset. PFA has been shown to be suitable for block construction in 2 ways. Firstly it produces a durable block that is resistant to the weathering action of the marine environment and secondly it has been shown that negligible leaching and subsequent bioaccumulation of metals contained within the block occurs. All ash products produced from the burning of coal are classified as 'inert'. Power producers are now charged £2 per tonne to land fill this inert product (non-inert products are charged £7 per tonne). This has come about through the advent of the 'Land Fill Tax'. This tax is likely to increase incrementally over several years.

'Washings' have, as far as the authors are aware, never been used in the construction of blocks for use in reef construction. This product has several advantages including its production in very large quantities near to potential reef sites (ie on the coast) and the fact that conventional disposal options are expensive (making reef construction an attractive alternative). However, there are several technical problems to overcome when attempting to manufacture concrete from such a fine aggregate. It is difficult to produce concrete which is durable enough to withstand the marine environment and yet still contains a low level of expensive ingredients such as cement. It is for this reason that the potential for the use of an ash product combined with washings as a means of manufacturing a suitable block should be investigated. The determination of whether it is economically and technically feasible to manufacture reef blocks using washings and ash is still to be determined and this problem is a priority for further research.

The process of implementing an artificial reef programme is outlined in Figure 1.

The current feasibility study has progressed to 'Site selection and licencing' (see figure 1) as users and purposes have been identified as well as possible sites and materials. Further research is required to identify the optimal site and finalise licencing requirements.

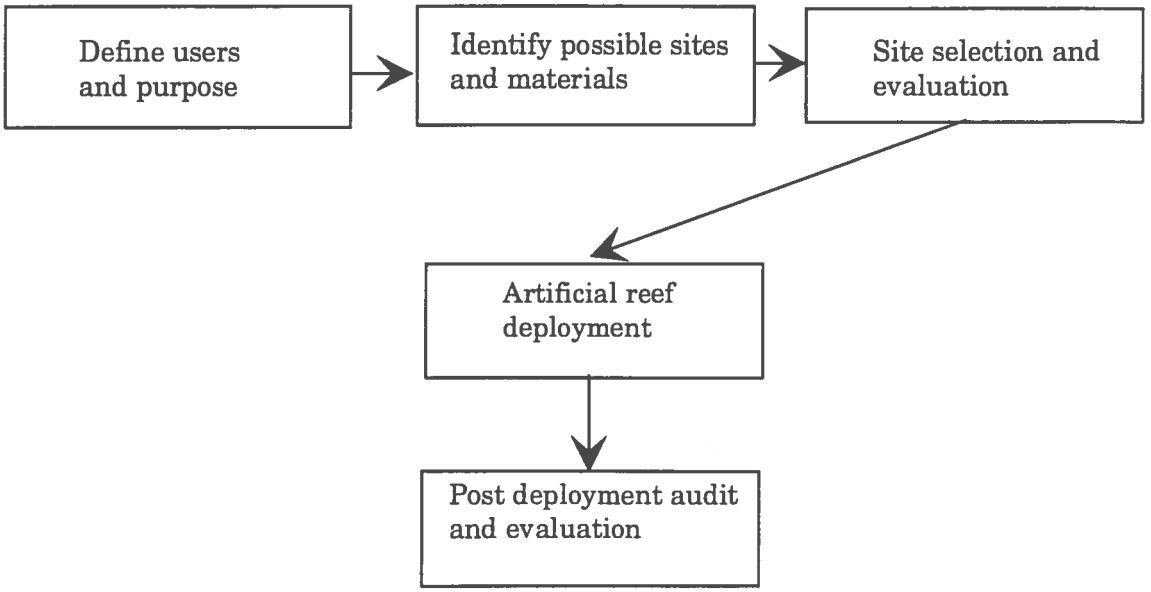


Figure 1 The processes leading to artificial reef construction

Subsection 4.1.2 Potential users of artificial reefs on the west coast of Scotland

Four potential uses of artificial reefs have been identified during the course of this feasibility study. These are:-

- Sport fishing
- Lobster ranching
- Sport diving
- Scientific research

Sport fishing is very under developed on the west coast of Scotland. Only two boats (The 'Magnum' and the 'Lady Jane') specialise in this sport in this area at the moment. Sport fishing is a multi million pound business in areas such as along the Atlantic coast of Ireland where a small number of fishermen started the industry relatively recently. Sport fishing on the west coast of Scotland is limited by several related factors which would be removed by the careful placing of an artificial reef. Currently boats such as the 'Magnum' need to travel considerable distances to find natural reefs. Reefs attract bait fish by providing shelter and food. The presence of the bait fish then attracts sport fish. A conveniently placed artificial reef would offer a near base, sheltered and accessible site for sport fishing. This would reduce the costs and overheads in operating sport fishing vessels in several ways. An offshore licence to take fee paying passengers as issued by The Department of Transport, is extremely demanding and requires a very high specification boat. This is costly but necessary in order to legally take fishermen to offshore natural reefs. The distance travelled takes time (which reduces fishing time) and fuel (which increases costs). A near shore artificial reef would allow boat operators with a less demanding licence to operate and would therefore encourage the development of this industry. This would bring all the benefits associated with increased tourism and provide opportunities for the diversification of the west coast fishing fleet which is likely to continue to decline under the proposed new restriction in fishing capacity imposed by the European Commission.

The lobster fishery is well established on the west coast of Scotland. Markets include the near continent where the high quality Scottish product demands a good

price. The resource is not infinite and hence the interest in the ranching of lobsters. Artificial reefs can be designed to provide a productive and safe environment for juveniles. Fishing (probably using existing creel gear) would take legal sized lobsters after approximately four to five years growth. A lobster ranching program offers several advantages over the wild fishery. It is sustainable and ecologically friendly. Production per unit effort would be greater than that from the wild caught fishery. The reef would be located in an ideal place for lobsters, any that migrated to natural reefs would add to the wild stock. Several factors currently prevent the development of lobster ranching. The main factor is the lack of legal protection. There is currently no legal mandate to prevent anyone fishing for lobsters in any location. Secondly, further research needs to be conducted into the requirements for juvenile lobsters in terms of the ideal habitat for their growth and survival, this research is ongoing. The development of a reef programme on the west coast of Scotland could accelerate such research and provide vital field data. The regulations governing Several Orders (which protect certain bivalve species at the moment) are likely to be amended to include lobsters at some date in the future. Lobster ranching appears to have considerable realisable potential especially along the west coast where water quality is very suitable and markets well established.

The reef attributes required by a lobster ranching and sport fishing reef are similar and there is considerable potential to combine these uses in a single reef.

Subsection 4.1.2 Research Requirements

This feasibility study has indicated that considerable economic benefit could result from the development of an artificial reef programme. Further research is required into several areas. These are outlined below.

4.1.2.1 Licencing. As part of the documentation that the Scottish Office would require to licence a reef proof of block durability is required. Evidence should show that the block will not disintegrate in marine conditions. The extent of the required proof needs to be ascertained to indicate the level of research that would answer such questions. Should the blocks contain an ash product then it is likely that the Scottish Office would require evidence to show the extent of leaching and subsequent bioaccumulation of components from the block. This could simply

consist of a literature search into the use of pulverised fuel ash in reef development programmes all over the world.

Further research is also required to investigate the direction of European legislation that is likely to govern reef development in the future. Representation should be made to the European Council if it can be shown that carefully managed reef programmes are beneficial to the marine environment and promote the economy of areas hard hit by, for example, European fishing restrictions.

As the licencing procedure would oblige any applicant to publicise any proposed reef development an idea of local (Argyll and/or Lochaber) opinion on reef development would be of use.

4.1.2.2 Block construction method and costs. Continued research is required into the most economical method of producing blocks suitable for use in reef construction. This will include the manufacture of test blocks using various combinations of cement, ash and waste aggregates. Whilst several different mixtures might give acceptable blocks the economics of block manufacture will change as the cost of ash disposal (through the landfill tax) and ash production increase.

Once a durable block is manufactured it needs to be tested in marine conditions. This could include the determination of the ingress of sulphate and other ions in to the block. This will indicate the long term block durability. An analysis of the costs of purchasing and running the plant required to bulk manufacture blocks needs to be done. These data will indicate the likely economic viability of such an operation.

Subsection 4.1.3 <u>The development of the reef programme</u>

Following research and licencing it is likely that prior to the development of the full scale reef a pilot would be built. This is likely to be relatively small (probably less than 100 tonnes) and will serve to show durability of blocks and the colonisation of the overall structure by encrusting organisms, fish and crustacea (crabs and lobsters). Once the experimental reef has been shown to be benign and robust in the marine environment then the development of a full scale artificial reef

programme could commence.

The programme would aim to be self financing with the block construction costs being met by the aggregate producers. This would depend on the relative costs of reef construction and alternative disposal routes.

A predicted timescale for an artificial reef development on the west coast of Scotland is detailed in annex 1.

5. BIBLIOGRAPHY

MAJOR TEXTS

Various papers in the Bulletin of Marine Science, Miami (1994) **55**, (2 & 3).

Seaman, W and Sprague, L M (1991) Artificial Habitats for marine and freshwater fisheries, Academic Press Inc. Harcourt Brace Javanovich, Publishers.

REFERENCES CITED IN TEXT

Branden, K. L. and Reimers, H. A. (1994) The development of 'environmentally friendly' tire reefs - 20 years of experience in South Australia. Bull Mar Sci (Miami), **55** (2-3), 1329 (abstract only)

Dhir, R. K., pers. comm., 1996

Greenwich Forum, 1994. Implications for the UK of the entry into force of the UN Convention on the Law of the Sea, Greenwich, London.

Jensen, A and Collins, K., (1996) Artificial reefs and oil platform decommissioning: an overview. Report to the Scientific Group on Decommissioning. Ref SUDO/TEC/96/2/C.

Pickering, H (1996) Legal issues on artificial reefs in the European Union. Paper presented at the European Artificial Reef Network Conference, Ancova, Italy, 22-30 March 1996.

Todd, C. D., Bentley, M. G. and Kinnear, J (1992) Torness Artificial Reef Project. Unpublished internal report to the SOAEFD, Marine Laboratory, Aberdeen

Whitmarsh, D J (1994) Economic analysis of lobster stock enhancement. Unpublished briefing paper for MAFF Directorate of fisheries research.

Whitmarsh, D., Pickering, H. Sarch, M. T. (1995) The economic appraisal of artificial reef structure for lobster production. Internal Report to Ministry of Agriculture Fisheries and Food.

PAPERS OF INTEREST

Alevison, W. S. and Gorham, J. C. (1989) Effects of artificial reef deployment on nearby resident fishes. Bull. Mar. Sci., **44**(2), 646- 661

Anderson, R. F., De Martini, E. E. and Roberts, D. A. (1989) The relationship between habitat structures, body size and distribution of fishes at a temperate artificial reef. Bull Marine Sci., **44**, 681 - 697.

Antsulevich, A. E (1994). Artificial reefs project for improvement of water quality and environmental enhancement of Neva Bay (St Petersburg County Region). Bull Mar Sci

Bannister, R. C. A. and Addison, J. T (1991) A large scale experiment to enhance a stock of lobster (*Homarus gammarus*) on the English east coast. ICES Mar. Sci. Symp., **192**, 99 - 107.

Bohnsack, J. A (1989). Are high densities of fishes at artificial reefs the result of habitat limitation or behavioural preference?. Bull. Mar. Sci. **44**, 631 - 645.

Brock, R. E. (1994) Beyond fisheries enhancement: artificial reefs and ecotourism. Bull Mar Sci. **55** (2-3), 1181 - 1188.

Calson, C. L. and Adriano, D. C. (1993). Environmental impacts of coal combustion residues. J. Envir. Quality, **22**(2), 227 - 247.

Collins, K. J., Jensen, A. C. and Lockwood, A. P. M. (1991) Artificial reefs using coal fired power station wastes constructively for fisheries enhancement. Oceanologica Acta, **11**, 225 - 229.

De Silva, M (1989) Artificial reef: a practical means to enhance living marine resources. In Chua, T. E. and Pauly, D. (eds) Coastal area management in South East Asia, 173 - 174.

Dunster, A. M. and Collins, R. J. (1990) Flue gas de-sulphurisation/ pulverised fuel ash cement stabilised blocks - marine durability studies following 12 months exposure. Client report CR 52/90 for the Central Electricity Research Laboratories, Building Research Establishment, Watford.

Gordan, W. R., (Jr) and Ditton, R. B. (1986) A user resource planning framework for offshore recreational artificial reefs. Coastal Zone Management Journal, **13**, 369 - 395.

Hockley, D. E. and van der Sloot, H. (1991) Long term processes in a stabilised coal-waste block exposed to seawater. Environ. Sci. Technol., **25**, 1408 - 1414.

Jensen, A. C., Collins, K. L., Lockwood, A. P. M., Mallinson, J. J. and Turnpenny, W. H. (1994). Colonisation and fishery potential of a coal ash artificial reef, Poole Bay, UK., Bull. Mar. Sci., **55**, (2-3), 1263 - 1276.

Labotka, A. L., Duedall, I. W., Harder, P. J. and Schlotter, N. J. (1985). Geochemical processes occurring in coal-waste blocks in the ocean, 718 - 739. In Duedall, I. W., Ester, D. R. Park, P. K. (eds), Wastes in the oceans, **4**, energy wastes in the ocean. John Wiley and Sons, New York.

Macdonald, J. M. (1994) Artificial reef debate: Habitat enhancement or waste disposal. Ocean Devaluate. and Int. Law, **25**, 87 - 118.

Redhill, F. J. and Oakey, S. A. (1985) Effects of seawater on the mineralogical and chemical composition of coal-waste blocks, 691 - 715. In Duedall, I. W., Ester, D. R. Park, P. K. (eds), Wastes in the oceans, **4**, energy wastes in the ocean. John Wiley and Sons, New York.

6. ACKNOWLEDGEMENTS

We would like to thank the 'Marine Resource Initiative' who part-funded this work and representatives of the numerous agencies and companies we contacted during the research phase of this desk study. In particular we would like to thank Professor R K Dhir (Concrete Technology Unit, University of Dundee), Dr Pickering and Dr Whitmarsh (CEMARE, University of Portsmouth), Dr Wickens (MAFF), Dr Dalziel (PowerGen Plc) and Mr R Hunter (Scottish Power) for their assistance in this feasibility study.

The list of companies, institutions and non-profit making organisations contacted during this study are listed below in alphabetical order.

Aberdeen University Research and Industrial Services (AURIS) Ltd
Alcan Smelting and Power UK
Big Game Club of Scotland
British Aluminium Plc
British Sub-Aqua Club
Building Research Establishment
Castle Cement Ltd
CEMARE, University of Portsmouth
Cement and Concrete Association
Concrete Advisory Service
Concrete Society
Concrete Technology Unit, University of Dundee
Crown Estate Commission
Department of Oceanography, University of Southampton
Foster (Movern) Yeoman (Glensander Quarry and main laboratories)
Halcrowe and Partners
International Centre for Island Technology (ICIT)
Lynemouth Power Station
MAFF Fisheries Laboratory, Conwy,
Marine Technology Centre, Strathclyde University
Marine Laboratory Aberdeen, Environmental Protection Section
Oban Coast Guard (Diving Liaison Officer)
Oban Tourist Office
Orkney Island Council
PADI International Ltd
PowerGen plc
Redland Aggregates
ScotSAC
Scottish Power Ash Sales, Longannet Power Station
SNH (Barcaldine and head office)

ANNEX 1 PREDICTED TIME SCALE FOR AN ARTIFICIAL REEF DEVELOPMENT

This annex gives an approximate timescale for an artificial reef development on the west coast of Scotland. It is assumed for the purposes of this estimate, that the reef will be of block construction, the blocks being made from a number of products stabilised with cement. The Dunstaffnage Marine Laboratory has, during this feasibility study, established a research link with the Concrete Technology Unit at the University of Dundee. The development of any new block construction will have to be thoroughly tested by the CTU, Dundee. The full scale production of blocks will, it is assumed, be taken on by the industry supplying the block constituents.

The following predictions on the likely time taken for a reef development are approximations. Factors likely to markedly influence the time taken for reef development include:

- Unknown requirements made by the Scottish Office
- Overcoming technical problems associated with block manufacture
- The consultation procedure may result in further delays. This will depend on representations made by concerned parties. Of particular importance are the interests of local fishermen.

An estimated timetable for the development of the artificial reef programme is given in table A1.

Abbreviations used in table A1:

DML - Dunstaffnage Marine Laboratory

CTU - Concrete Technology Unit, University of Dundee

IND - Industry

Table A1 Approximate Timescale for the development of an artificial reef programme

TASK	LAB	YEAR								
		1				2				3-4
		month				month				
		3	6	9	12	3	6	9	12	
(i) General / legal / licencing										
Literature search	DML									
Determine licencing requirements	DML									
Legal arrangements (liability, ownership)	DML									
Licence application and processing	DML									
(ii) Block manufacture										
Determine method of block manufacture	CTU									
Monitor ingress of sulphate	CTU									
Monitor extent of leaching	CTU/DML									
Small scale block construction	CTU									
Large scale block construction	IND									
Reef deployment	IND									
Monitor long term performance	DML									
(iii) Site Selection										
Consult relevant authorities (SNH, SEPA etc)	DML/IND									
Arrange lease (from Crown Estate Office)	DML/IND									
Consultation process (CP)	DML									
Reply to concerns raised during CP	DML/IND									
Select site	DML									
(iv) Biological monitoring										
Establish techniques	DML									
Monitor leaching/ bioaccumulation	DML									
Monitor community development	DML									
Continued biological audit and site evaluation	DML									
(v) Costing										
Block construction (materials and plant)	IND									
Licencing/ deployment costs	IND									
Cost benefit analysis	IND									