THE POTENTIAL FOR ARTIFICIAL REEFS BASED ON AGGREGATE BY-PRODUCTS

Wilding, Thomas; Sayer, Martin

Publication date:
1997

THE POTENTIAL FOR ARTIFICIAL REEFS BASED ON AGGREGATE BY-PRODUCTS

Final Report

The Waste Management Group

Prepared for Foster Yeoman Limited by:
Mr. Thomas A. Wilding and Dr. Martin D. J. Sayer
Tel: 01631 567814
Fax: 01631 565518
E-mail tomw@dml.ac.uk
October 1997

Contents **Page**

Contents ………………………………………………………………………….. 2

List of tables and figures ………………………………………………………. 2

Executive summary ……………………………………………………………. 3

1. Introduction ……………………..…………………………………………….. 4

2. Artificial reef construction……………………..………………………….. 5
2.1 Block manufacture …………………………………………………….. 5
2.2 Site selection …………………………………………………………… 6
2.2.1 RoxAnn survey ……………………….……………………….. 9
2.2.2 Video/diver survey ………………………………………………. 12
2.3 Licensing ………………..…………………………………………….…. 12
2.3.1 Legal background………………………………………………… 12
2.3.2 Marine construction works licence ……………………………. 14
2.3.3 Crown Estate ………………………………………………….. 15
2.3.4 Department of Transport ………………………………………. 16

3. The proposed artificial reef programme ………………………………….. 16
3.1 Size and design ……………………………………………………….. 16
3.2. Proposed scientific programme ……………………………………… 17
3.3 Lobster ranching …………………………………………………….. 18
3.4 Funding ……………………………………………………………….. 19
3.4.1 The Waste Management Group ……………………………….. 19

4. Conclusions ……………………………………………………………………. 20

5. Acknowledgements ……………………………………………………………… 21

6. References ……………………………………..…………………………….. 22

Annex 1 - Proposed scientific programme …………………………………… 24
Annex 2 - Waste Management Group constitution ………………………… 34

List of figures and tables

Figure 1 *Admiralty Chart showing proposed reef site.*

Figure 2 *Bathymetry at the proposed reef site.*

Figure 3 *Roughness at the proposed reef site.*

Figure 4 *Hardness at the proposed reef site.*

Figure 5 *Schematic representation of the proposed artificial reef complex showing twenty four reef modules of the same design.*

Table 1 *Summary of trial mix data*

Executive Summary
Artificial reefs are man-made structures deployed on the sea floor which simulate natural reefs in some way. They can be used for a variety purposes including fishery enhancement and sea defences. Artificial reefs range in size from modest experimental reefs (50 - 100 tonnes) to massive full scale coastal defence works which weigh in excess of 100,000 tonnes. Construction materials range from decommissioned oil platforms to less controversial concrete blocks.

In an earlier report (Wilding and Sayer 1996) artificial reefs were identified as having potential on the west coast of Scotland as a pro-active method of aggregate by-product utilisation which, when built, could have positive benefits for the local economy. Foster Yeoman Limited, operate a large quarry on the west coast of Scotland and produce several by-product streams which currently have limited value and which could be used in the production of blocks for use in artificial reefs. Foster Yeoman Limited commissioned the current research which had the remit of determining the cost effectiveness of block manufacture using aggregate by-products, finding a suitable deployment site, investigating reef designs and sizes, opening communications with the licensing authority and calculating the funds required to construct the reef and run the associated scientific programme.

The research has indicated that an artificial reef development could benefit Foster Yeoman Limited in terms of product development and, as an experimental facility, help resolve some of the scientific and socio-economic issues associated with artificial reefs. An artificial reef has been proposed consisting of 50,000 tonnes of aggregate by-product based concrete blocks divided between 24 reef modules. A suitable site of ca. 16 hectares has been identified on the east side of Lismore in the Lynn of Lorne though negotiations are still underway with local fishermen. The reef complex will employ a variety of block designs, reef unit designs and deployment depths and allow for elements of fishery ecology, biodiversity modification, benthic disturbance and hydrographical interference to be investigated. Initiating these research programmes for at least two years prior to reef deployment will give an unique opportunity to undertake proper pre-deployment research. This element, often lacking in other reef studies, will allow pre- and post-reef deployment comparisons and thereby allow determination, in a systematic fashion, of the value of artificial reefs. The proposed reef complex will examine the commercial viability of lobster ranching and how the reef can be designed to maximise the return from this type of enterprise.

The research will assist in the development of artificial reef technology and could encourage the adoption of reef-based fisheries all over Scotland. This may lead to the development of a substantial market for artificial reef blocks.

1. Introduction

Research commissioned by the Marine Resource Initiative (MRI) in 1996 identified the potential for artificial reefs on the west coast of Scotland (Wilding and Sayer 1996). The MRI report was generic in that, whilst identifying potential user groups, it was not aimed at any particular stakeholder. The MRI report identified the cost of materials as an important factor in determining the viability of artificial reefs but also noted that, to date, much of the research regarding the efficacy of artificial reefs was limited and further research was required.

Foster Yeoman Limited operate a large quarry at Glensanda where rock is blasted from the rock face, crushed and then separated. To reduce the visual impact of the quarry, primary processed aggregate (containing 20-25% scalpings) is conveyed to a 300 metre deep vertical tunnel (the 'glory hole') down which it passes. It is then conveyed horizontally via an 1800 metre tunnel to secondary processing facilities. The passage of the aggregate down the glory hole generates further scalpings; as a result of the glory hole method of transport this low value product (aggregate <40mm diameter) make up ca. 42% of the total quarry output, twice that that would be generated using conventional methods of quarrying. Glensanda currently generates some 1.9 million tonnes of scalpings which are shipped to markets for reprocessing. Processing basically separates the scalpings into aggregates and sands (high value) with the finest material (zero value) being removed by hydrocyclones. Changes in markets have made it desirable to wash the aggregate on site and a washing facility is due to come on-stream, at Glensanda, in the spring of 1998. The finest material is produced as a filter-cake containing ca. 40% water. It is predicted that the Glensanda facility will produce ca. 100,000 tonnes of filter-cake by-product per annum. Whilst permission for on-site storage for up to five years has been granted the filter-cake currently has no value and poses a disposal problem.

Foster Yeoman Limited, funded the current research to investigate the potential for the use of the filter-cake by-product in the manufacture of concrete blocks and their subsequent suitability for use in an artificial reef, the final objective being the production of artificial reef blocks for commercial sale. The Dunstaffnage Marine Laboratory are aware of the value of an experimental artificial reef as a research facility in addressing some fundamental and applied scientific problems related to both artificial reefs and more generic issues such as the factors controlling biodiversity. These elements are detailed in the scientific programme (Annex 1). One element of particular interest and relevance to artificial reefs is that of the ranching of lobsters. Artificial reef-based lobster ranching, if successful, would offer a real and sustainable alternative to wild stock fishing to fishery-dependent communities without requiring a radical (and undesirable) lifestyle change.

The purpose of this report is to detail progress made during the Foster Yeoman Limited, funded contract and to suggest how the proposed reef development can be taken forward.

The objectives of this second, more specific, feasibility study were to:-

- establish specific objectives of concerned parties
- examine the viability of utilising a filter cake by-product in reef block manufacture

! identify acceptable locations for reef deployment
! assess reef designs and approximate size(s) of deployment
! establish communications with licensing authorities
! establish scientific objectives associated with an artificial reef deployment
! to estimate funding levels for deployment and subsequent scientific baseline research
! identify sources of funding additional to the required baseline funding
! involve local fishing and recreational interests in a consultation exercise.

2. Artificial reef construction

The process of constructing an artificial reef can be divided into three main phases. These are (i) construction material research and development, (ii) site selection and (iii) licensing. Block performance data and site details are a pre-requisite to the licensing of the proposed reef.

2.1 Block Manufacture

One of the main research priorities was to determine if, and how, the filter-cake aggregate by-product produced by the washing of aggregates can be used as the primary constituent in block manufacture. Initial research into block manufacture was contracted out to Construction Materials Management (CMM). Preliminary results have been encouraging and it is considered that, with further research, building blocks meeting British Standards will be produced using the filter-cake by-product. A summary of preliminary trial mix results is shown in table 1.

Mix No	Stabilising material (%)				Strength (N/mm^2)
	Quicklime	Cement	Flyash	Granite dust	
3	10	0	50	0	7.0
6	0	10	50	0	8.0
9	0	10	10	42	3.5
10	0	5	20	30	1.5

Table 1 *Summary of trial mix data*

It is thought (Worters, pers. comm.) that a strength of at least 10 N/mm^2 will be required for blocks used in artificial reefs.

CMM identified the following problems regarding the use of the filter-cake in concrete manufacture (Worters 1997):-

1. The moisture content is too high (at ca. 42%)
2. As a consequence of the high water content the energy from pozzolans such as quicklime has not been used in the cementing process
3. Globules of filter-cake persist in the concrete unless a coarser grit is included.
4. Fly ash alone shows little potential as a stabiliser. Cement or quicklime is required to activate the fly ash.

CMM made the following recommendations:

1. The moisture content of the filter-cake should be reduced. It may be possible to do this by adding dry dust from the dust extraction plant.

2. The elimination of filter-cake globules must be achieved (the presence of these flaws may significantly reduce the strength of the blocks)
3. That the artificial reef blocks be manufactured alongside more conventional blocks which would allow plant sharing and reduce costs.

Any block that is to be used for the construction of an artificial reef must be strong enough to survive on-shore handling and the rigours of deployment without breaking in addition to having a long life in the marine environment. The block manufacturing process must allow for the inclusion of voids (i.e. a hole) in the block to enable the testing of habitat complexity on reef performance. Habitat complexity has been identified as an important factor governing colonisation of marine structures {Seaman, 1996 #25; Spanier, 1996 #24}. This requirement may require the block to be further strengthened and would be a priority research area should the pre-deployment research be initiated.

2.2 Site Selection

The first task in identifying potential sites was the consideration of key criteria from the different perspectives of the concerned parties, which are Foster Yeoman Limited, Dunstaffnage Marine Laboratory and potential site users (i.e. commercial fishing interests). Distance from the production plant was a key consideration for Foster Yeoman Limited, as increased travel would increase deployment costs. The Dunstaffnage Marine Laboratory required a site that was local (for logistical reasons), in the correct depth range to allow reef observation using SCUBA technology (between 10 and 30 metres), have the correct substratum type to support the physical structure of the blocks (i.e. to prevent them sinking) but soft enough to support juvenile life stages of species such as the lobster. In addition the site must be outwith strong tidal currents (which could move blocks and interfere with the foraging behaviour of species such as the lobster) but have sufficient water exchange to prevent hypoxic conditions developing. Of prime importance and the major factor governing site identification were commercial fishing interests. The artificial reef site must not interfere with legitimate fishing activity. This is important for two reasons; firstly, objections from fishermen regarding the site would make gaining the appropriate construction licences difficult or impossible, and secondly good relations with fishermen and the local populous are crucial given that the aims of some of the research is to increase the potential use of artificial reefs (to produce lobsters for example).

A meeting was arranged with representatives from the Mallaig and North West Fishermen's Association (MNWFA) to discuss reef siting and to ensure that the proposed reef would not interfere with fishing activities. A site in the Lynn of Lorne was suggested by these representatives on the east side of Lismore, to the north of Eilean Dubh. It is proposed to site the reef within the box drawn in Figure 1. The proposed site was surveyed by RoxAnn (a recently developed sea bed discrimination system), diver and using a towed video camera in order to assess its acceptability to the artificial reef project.

(THIS FIGURE HAS BEEN DELETED TO SAVE N DRIVE SPACE

A COPY IS ON FIN_REF. DOC)

Figure 1 *Admiralty Chart showing proposed reef site.*

2.2.1 RoxAnn Survey

RoxAnn is an acoustic mapping system that has been developed for remote mapping of relatively large areas of seafloor. The system relies on the interpretation of ship-generated acoustic signals after they have reflected off the seafloor. The reflected signals alter according to the hardness and roughness of the seafloor. For numerous points along the path of the vessels travel, data representing the hardness and roughness of the seafloor in addition to the depth and latitude/longitude are recorded. This is then collated and extrapolated to produce two and three dimensional images of the bottom type and depth of the surveyed area. Ground truthing is required to allow for the comparison of hardness: roughness ratios and observed bottom types. The resolution and accuracy of the computer interpolation is dependant on the amount of data points gathered per unit area. The proposed site was surveyed using the RoxAnn system and the results are shown in Figures 2, 3, and 4.

The axes in Figures 2 and 3 represent Ordinance Survey eastings and northings. Values in Figure 2 represent depths in metres, the proposed reef modules are shown by the purple squares and are approximately 40 metres square. Three sets of eight modules at three distinct depth ranges are shown. Values in Figures 3a and 3b are arbitrary measurements of roughness and hardness; the tracks denote the passage of the boat on this particular survey and are not shown on Figure 2 for clarity. Values for all parameters between the tracks are calculated by comparisons with the nearest known data, however predictions will be made even in the absence of proximal data. The computer software (‘Surfer’) has generated predictions for all parameters (depth etc.) in the north-west part of the surveyed area (where there are no tracks). This part actually contains part of Lismore as shown on Figure 2 and emphasises the care that must be taken when using this versatile system.

(THIS FIGURE HAS BEEN DELETED TO SAVE N DRIVE SPACE
A COPY IS ON FIN_REF. DOC)

Figure 2 *Bathymetry of the proposed reef site.*

(THIS FIGURE HAS BEEN DELETED TO SAVE N DRIVE SPACE A COPY IS ON FIN_REF. DOC)

Figure 3a *Roughness of the seafloor at the proposed reef site*

(THIS FIGURE HAS BEEN DELETED TO SAVE N DRIVE SPACE A COPY IS ON FIN_REF. DOC)

Figures 3b *Hardness of the seafloor at the proposed reef site.*

2.2.2. Video/diver survey

Two diving surveys were conducted in two contrasting areas within the proposed reef site. The first survey roughly followed the 22 metre contour at the southern end of the site. The sediment was generally a sandy mud containing shell fragments overlain with stones and cobbles ranging from ca. 0.1 to 0.3 metres in diameter. The extent of the cover also varied, subsequent video surveys showed this variation to be independent of depth. Surprisingly there appears to be no significant increase in stone extent or size as the depth decreased. The mega fauna was dominated by *Asterias rubens, Crossaster papposus, Echinus esculentus, Liocarcinus sp., Sabella sp* and *Aequipecten opercularis*. Allowing for the restrictions imposed by a single, non-quantitative survey the site did not exhibit any unusual fauna or flora or any other unusual features. The second dive survey started at 14 metres and finished at ca. 8 metres. The sediment and biota changed over the depth, with the shallower areas being covered in a dense algal/ hydroid turf. This turf is likely to colonise the shallower reef and provide an interesting insight into the effects of such flora on the subsequent colonisation and block performance.

An extensive towed video survey was conducted to provide a more general overview of the site and to allow the ground truthing of RoxAnn. The video showed the sea floor to be fairly consistent with variations in the amount of stone/ shell cover.

The initial survey has indicated that the site is ideal for the placement of an artificial reef. Further research is proposed to determine if the sediment can support the reef blocks (i.e. prevent them sinking) together with a hydrographic survey.

2.3 Licensing

Licensing is the last consideration for the proposal process for artificial reef deployment. The licence application, if it is to be successful, must be accompanied with evidence of the inert (non-harmful) nature and the robustness of the construction materials. Department of Transport section 34 consents and a lease from the Crown Estate are also required. The legal background to the licensing process and details regarding the other permits and leases are discussed below.

2.3.1 Legal Background

The United Nations Convention on the Law of the Sea (UNCLOS III) defined the construction of artificial reefs as ‘dumping’. As such, reef construction falls under the London Dumping Convention, 1975 and the Convention for the Protection of the Marine Environment of the North East Atlantic ((which supersedes, combines and extends the provisions of the Oslo Convention (1972) and Paris Convention (1974)) amongst other international conventions (Pickering 1996). Under provisions in the London Dumping Convention and the Convention for the Protection of the Marine Environment of the North East Atlantic the Secretary of State for Scotland is responsible for the licensing of marine dumping (Whitmarsh et al. 1995). This is achieved through the implementation of the Food and Environment Protection Act (1985) (FEPA), which, in Scotland is undertaken by the Scottish Office Agriculture, Environment and Fisheries Department (SOAEFD) (the Scottish

Office). Under FEPA, marine dumping is divided into three categories relating to the proposed material. These are:

- licence to deposit solid waste (e.g. dredged material/fly ash, colliery waste etc.);
- licence for sea disposal of bulky wastes (includes decommissioned oil production platforms/rigs) and
- licence for marine construction works.

International dumping conventions stipulate that heavy metals cannot be dumped at sea. However, they also state that artificial reef development should be permitted so long as it can be shown that the reef does not harm the marine environment. Coal ash is an essential part of the proposed reef as it is a cost-effective pozzolan. However, coal ash contains trace amounts of heavy metals. International conventions explicitly ban the marine dumping of such metals and the debate is on-going as to whether the use of ash in the manufacture of artificial reef blocks and the subsequent placement of these blocks contravenes the conventions. Currently the Scottish Office require evidence that the blocks do not harm the marine environment - in the case of the proposed reef blocks, the work done by the Southampton Oceanography Centre {Collins, 1992 #8; Collins, 1994 #9; Collins, 1995 #7} is considered suitable. Communication with the Scottish Office has revealed that it is very unlikely that they will require pre-deployment leaching studies on the proposed blocks and would accept previously published research on the leaching characteristics of concrete containing fly ash. Preliminary leaching studies were not initiated prior to the application of the licence application for this reason. Leaching studies would, however, be required as part of the reef performance audit and would be initiated after the deployment of the reef in addition to some systematic laboratory research during the pre-deployment phase (see Annex 1).

During the MRI-funded research the issue of the potential requirement for reef removal and site restoration was identified as a particular problem. Artificial reefs constructed using, for example, decommissioned oil rigs have a long but finite life span. The Scottish Office has required evidence in the past to show that such a reef would, when it had finished serving its initial purpose, be removed. The costs of removing a corroded semi-buried massive steel structure would be enormous. This requirement halted the development of reef programmes which proposed the use of high profile steel structures (i.e. decommissioned oil rigs) in the construction of artificial reefs. The requirement to remove the reef when it no longer continues to serve the function for which it was originally designed does not apply to concrete block artificial reefs. This concession is very important, the costs of removing a substantial block reef would be massive and result in an on-shore disposal problem. The Scottish Office have acknowledged that the proposed reef, once deployed, will be there for perpetuity.

A reef constructed using concrete blocks would require a marine construction works licence. This licence is the least politically contentious, most straightforward to obtain and does not require a Best Practical Environmental Option (BPEO) review. This is discussed below.

2.3.2 Marine construction works licence

In assessing an application for a marine construction works licence the Scottish Office must be assured that the reef materials do not constitute any threat to the marine environment, marine resources and, importantly, to any user of the artificial reef site. They also consult various statutory bodies such as the Scottish National Heritage (SNH) and Scottish Environment Protection Agency (SEPA) to assess their views. During the course of the current research both these organisations have been contacted and informed of the reef construction proposal. The SNH were, broadly speaking, in favour of the development. Their main concern stemmed from the impact the reef may have on outcrops of limestone on Lismore. The proposed reef is not near such outcrops and it is considered unlikely that objections will be raised by this group. SEPA were similarly unconcerned with the development.

The most important users of the west coast are the fishermen. This group were informed of the proposal early on and were consulted and subsequently suggested a suitable site. This important aspect is discussed in 2.2.

In summary, in assessing the application for a construction works licence the Scottish Office has to be assured that:-

(i) the block will not break up (physical integrity) or leach heavy metals (chemical integrity);
(ii) the placement of the reef will not interfere with existing fishing or other user community activity;
(iii) the purpose of the reef is not waste disposal and
(iv) fishery enhancement is not the sole reason for reef deployment.

The cost of the marine construction works licence depends on the cost of the works: for works costing in excess of £26,125 the licence application (non-refundable minimum) costs £1,045. This is the likely tariff for the proposed reef given that estimates of the cost of reef deployment are £100,000 (Larson, pers. comm. 1997).

2.3.3 Crown Estate

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 Commission (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.

In terms of planning, the Crown Estate Office would not be involved except where there was an existing Crown Estate tenant in the near vacinity of the proposed development. The existing tenant would be consulted and any legitimate concerns would need to be addressed. The proposed reef site lies near an existing scallop farm which will have a Crown Estate licence. The scallop farm (Lismore Seafoods Limited) is owned by Mr Gillespie Black who has been consulted regarding the proposed reef development and, whilst requesting further details, appears satisfied that it will not adversely affect his operation.

The cost of the lease is subject to negotiation with the Crown Estate. Should the figure suggested by their managing agents be considered unreasonable, an independent arbitrator can be employed to make a final decision. The grantee of all Crown Estate consents is responsible for meeting the Crown Estate's solicitor's fees, agents fees, plans costs and any stamp duty. Formally applying for an estimation of the likely lease cost initiates the legal process and thus the fees. For this reason, the process has not been started. The cost of the lease is likely to reflect the revenue coming from the reef; this will be negligible in the early stages of the development as the primary purpose will be purely scientific. The lease period is subject to negotiation but is likely to be every five to ten years. Renewal of the lease will be dependent on continued complicity with regulations stipulated by the Scottish Office. Given that this condition is met, the lease would be renewed for perpetuity. Should any planning applications be made to the Crown Estate that may effect the artificial reef, then the Dunstaffnage Marine Laboratory would be consulted and any objections considered and taken into account when granting any additional licences.

Ownership confers liability and is therefore an important issue. During discussions with Foster Yeoman Limited, it was decided that the Dunstaffnage Marine Laboratory would 'own' the reef and formally apply to the Scottish Office for the construction works licence and apply for the lease from the Crown Estate. The reef owner is liable to pay for the site lease which is a substantial commitment as the reef will exist for perpetuity.

2.3.4 Department of Transport

Submarine constructions including artificial reefs can require a section 34 consent from the Department of Transport (DoT). The DoT, in conjunction with the Northern Lighthouse Board would determine if the construction posed any risk to shipping and the nature of any buoyage required. Given the remoteness of the proposed site which lies outside shipping lanes it is thought that gaining this permit should be a formality. A section 34 consent will be sought as soon as the exact location of the proposed reef has been finalised and licence applications made. Initial contacts have indicated that any construction that draws less than 10 metres will require buoyage.

3. The Proposed Artificial Reef Programme

Research to date has indicated that there is no reason why the artificial reef should not be constructed. All the major hurdles have been overcome: a suitable site has been located, site users have been contacted and the licensing authority has indicated that the proposed construction materials would meet with their approval. A reef plan and the pre- and post-deployment research has therefore been formulated and is detailed below. The development of lobster ranching technology is a major driving force in the proposed reef programme and is also discussed.

3.1 Size and design

The proposed reef will be constructed using concrete blocks manufactured at Glensanda. The total size of the reef complex will be of the order of 50,000 tonnes, deployed between 24 separate reef modules (ca. 2080 tonnes for each module) over an area of approximately 16 hectares. The reef units will be designed to test three factors affecting reef performance: these are depth of deployment, block design and reef design. Each combination will be replicated to make comparisons statistically valid. It is envisaged that the reef blocks will be transported to the reef site by a vessel operated by Foster Yeoman Limited, with a capacity of ca. 400

tonnes per trip (5 trips per reef module). How each load can be accurately deployed requires further research. The spread of the blocks as they descend through the water column will, to some extent, determine the shape of the reef. Complex shaped reef modules may be formed by the accurate deployment of each load giving different reef shapes. In the case of full-scale deployments the scientific ideal may have to be significantly modified for logistical reasons.

A schematic representation of the reef is shown in figure 5. The illustration does not show differing reef designs.

(THIS FIGURE HAS BEEN DELETED TO SAVE N DRIVE SPACE
A COPY IS ON FIN_REF. DOC)

Figure 5 *Schematic representation of the proposed artificial reef complex showing twenty four reef modules*

The artificial reef design will continue to have input from local communities in many aspects of its development. Consultation will continue to ensure that the reef is designed to allow creel fishing (creel fishing is the preferred method for lobster fishing locally). It is hoped that, once established, reef management will be transferred to local fishermen. This will enhance the perception of artificial reefs by both local communities and local/ regional government and maximise the economic benefits derived from the reef by fishing communities.

3.2 Proposed Scientific Programme

A summary of the scientific programme is supplied here, full details of the programme are in Annex 1. The initial scientific programme can be divided into two phases. Phase I will be a pre-deployment site assessment combined with the finalisation of the block constituents, block deployment method and reef design. Laboratory leaching studies will also form part of the pre-deployment research in addition to the collection of baseline biological, hydrographical, biogeochemical and socio-economic data. It is expected that this phase will last approximately two years. Phase I will culminate in the deployment of the artificial reef. The baseline scientific data generated will increase the value of the subsequent scientific research. The deliverables from Phase I are summarised below.

Phase I Deliverables

The objectives of the initial 2 year programme are:

1. *To ascertain the most cost-effective block mixture which will deliver the required block strength and leaching characteristics.*
2. *To finalise block and reef design.*
3. *To estimate past sedimentation rates and thus generate predictions on the reef impact on bedload transport.*
4. *To finalise a block deployment method which will minimise dispersion allowing accurate placement of individual reef modules over the depth range.*
5. *To predict 50 year wave extremes and monitor meteorological data for the site to allow predictions of storm damage.*
6. *To collate biological, hydrographical, biogeochemical and socio-economic data on which to base post-deployment comparisons.*

Phase II is the post-deployment site survey and environmental impact assessment. The research will follow on from the pre-deployment research and aim to answer some of the fundamental questions relating to biodiversity and fisheries ecology. A detailed scientific programme for Phase II will depend largely on the results from Phase I, an overview of the proposed research is given in Annex 1.

3.3 Lobster Ranching

Until recently there were no *de jure* property rights in respect of lobsters (Whitmarsh et al. 1995). This meant that no-one could own lobsters as they freely roamed on the seafloor. This did not apply to other shellfish species such as scallops and oysters which were included in the Sea Fisheries (Shellfish) Act, 1967 (s. 1), Shellfish (specification of molluscs) Regulations 1987, SI 1987/218. This legislation allowed ownership of named species as they remained on the seafloor. The legislation allows the granting of Several or Regulating Orders over a specified area of seafloor. The Several Order owner has exclusive rights to fish named species within specific boundaries. This has resulted in the small-scale development of scallop ranching where juvenile scallops are grown and released to be re-captured when they are of a legal size. A recent change in the legislation has meant that lobsters are now included under the Sea Fisheries (Shellfish) Act. This has resulted in an increased interest in the potential for lobster ranching. An artificial reef development could be the basis for an application for a Several or Regulating Order.

Work is continuing at the Centre for Environment, Fisheries and Aquaculture Sciences (CEFAS) Conwy, North Wales (Wickins and Barker 1996) to design reef blocks or arrangements of reef blocks which create the best lobster habitat. 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 should indicate areas where lobster growth is likely to be optimal and the costs of the reef can be reduced using waste aggregates. Furthermore, ongoing research will indicate the optimal reef design in terms of suitability for lobsters which could increase the profitability still further (Whitmarsh et al. 1995). Collaborative links have been established with the CEFAS group.

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 {Wickins, 1996 #10; Wickins, 1996 #11}. 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 some time (as yet unknown but to be assessed) 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) (Addison et al. 1994; Bannister et al. 1994). Research indicates that it may be possible to design a reef that maximises the numbers of the preferred food items for lobsters (Spanier 1994).

3.4 Funding

Funding the initial 2 year programme could be problematical because most funding bodies are ‘results led’. The pre-deployment phase will not generate conclusive results but rather provide the foundation for the post-deployment research. Such pre-deployment research is often lacking in other artificial reef programmes much to their detriment (see Annex 1). Funding is being sought from the Ash Association and Local Enterprise Councils. Other potential sources of funding include the Highland Regional Council.

3.4.1 The Waste Management Group

Since October 1996 all waste disposed to landfill sites is charged the Landfill Tax. This tax (currently £2 per tonne for inert waste and £7 per tonne for everything else) was introduced in an attempt to reduce the volume of waste going to landfill sites. Under the new legislation (Finance Act, 1996: The Landfill Tax Regulations (SI 1996 No. 1527)) landfill site operators can claim back 90% of any contribution they make to researching methods of reducing the demand for landfill. However, these site operators can only claim back contributions they make to enrolled ‘Environmental Bodies’.

The Environmental Trust Scheme Regulatory Body Limited (Entrust), was established to regulate and enrol organisations as Environmental Bodies under the Landfill Tax Regulations. Once enrolled, environmental bodies can apply to licensed landfill site operators for funding to further objectives including ‘research and development ….. to encourage the use of more sustainable waste management practices’. Within the Dunstaffnage Marine Laboratory a group named the Waste Management Group was established during the period of the present study and enrolled as an Environmental Body. The constitution of this group is shown in Annex 2. Landfill operators can fund research into methods of reducing the use of landfill sites through the Waste Management Group and claim 90% of their contribution back as landfill tax credits.

Coal-fired electricity stations produce large amounts of ash of various types. Currently one half of this material is sold for use in the construction industry and as an additive to cement. The other half poses a disposal problem for the electricity generators and, as licensed landfill site operators, they are liable to pay £2 per tonne to landfill excess ash within their own landfill sites. The Ash Association is a group consisting of representatives from the major ash producers in the UK. The function of the Ash Association is to co-ordinate research into new ways of ash utilisation leading to a larger market for their product. The Ash Association is interested in the artificial reef project because the blocks will contain ca. 20% ash (and therefore will require at least 10,000 tonnes of ash). Whilst this is a relatively small amount compared to total production (ScottishPower's station Longannet alone produces ca. 1 million tonnes per year) the potential market for ash as a constituent of artificial reefs could be substantial, and therefore worthy of study.

4. Conclusions

The largest experimental reef in Europe could, following a successful licence application, be constructed on the east side of Lismore in Argyll. Whilst further research into the block design and manufacture is required for a marine construction works licence application the major hurdle of acceptance by the fishing community has largely been overcome. The project now depends on the successful procurement of funds for the two year pre-deployment research. Once this has been achieved the authors are optimistic that the proposed reef will proceed provided that there are no significant political changes regulating marine 'dumping'.

5. Acknowledgements

The authors would like to express their gratitude to the sponsors of this research, namely Foster Yeoman Limited Our thanks also to the crews of the Calanus and Seol Mara who assisted in the site surveys, to the late Neil MacDougall for assistance in the use of RoxAnn, to Hugh Allen and Ross Campbell for assistance in site selection and their support and also to Alistair Bullock for his advice and guidance. Our thanks also to Ron Hunter of ScottishPower Ash Sales, Derek Saward for advice on reef licensing and John Wickins for information concerning lobsters. Finally thanks to David Hughes for his assistance with the initial biological survey.

6. References

Addison J.T., Bannister R., A. C., 1994. Re-stocking and enhancement of clawed lobster stocks: a review. Crustaceana 67 (2), 131-155

Bannister R.C.A., Addison J.T., Lovewell S.R.J., 1994. Growth, movement, recapture rate and survival of hatchery-reared lobsters (*Homarus gammarus* (Linnaeus, 1758)) released into the wild on the English east coast. Crustaceana 67 (2), 156-172

Collins K.J., Jensen A.C., 1995. Stabilised coal ash artificial reef studies. Chemistry and Ecology 10, 193-203

Collins K.J., Jensen A.C., Lockwood A.P.M., 1992. Stability of a coal waste artificial reef. Chemistry and Ecology 6, 79-93

Harmelin J.-G., Bellan-Santini D. (1996) Assessment of biomass and production of artificial reef communities. In: Jensen AC (ed) First European Artificial Reef Research Network Conference. Southampton Oceanography Centre, Ancona, Italy, pp 305-322

Pickering H., 1996. Artificial reefs of bulk waste materials: a scientific and legal review of the suitability of using the cement stabilised by-products of coal-fired power stations. Marine Policy 20 (6), 483-497

Spanier E., 1994. What are the characteristics of a good artificial reef for lobsters. Crustaceana 67 (2), 173-186

Whitmarsh D., Pickering H., Sarch M.T. 1995. Economic appraisal of artificial reef structures for lobster production - final report. Centre for Coastal Zone Management, University of Portsmouth

Wickins J., Barker G. (1996) Quantifying complexity in rock reefs. In: Jensen AC (ed) First European Artificial Reef Research Network Conference. Southampton Oceanography Centre, Ancona, Italy, pp 423-430

Wilding T.A., Sayer M.D.J. 1996. Artificial reefs on the west coast of Scotland: A feasibility study. The Scottish Association for Marine Science, 203, Oban, Scotland

Worters P. 1997. Study of stabilisation of granite filter cake from Glensanda and potential for use in manufacture of blocks suitable for artificial reef formation. Construction Materials Management, CMM 041-97-1

ANNEX 1

The purpose of this annex is to introduce the concept of artificial reef research and give a summary of associated issues and problems and an overview of the proposed reef. The methods proposed by the Dunstaffnage Marine Laboratory Waste Management Group to address and resolve some of these fundamental issues are discussed.

Introduction

An artificial reef is a man-made structure, placed usually in an area devoid of habitat complexity for reasons as far ranging as coastal protection, fishery enhancement and waste disposal. Increasingly, artificial reefs have attracted a body of scientific interest which is involved in investigations into the performance of the reef itself or related scientific issues.

Artificial reef research has, in general, been compromised in the past because scientific objectives have not been the primary reason for deployment. Research has often been commissioned after the reef has been established, with the researchers having no input into reef design. The results from research conducted under these imposed conditions are therefore often perceived poorly by scientific peers, and, as a consequence, science relating to artificial reefs has a poor reputation. However, this detracts from the excellent opportunities afforded to the scientific community from a substantial artificial reef deployment which is planned and executed with scientific research as the primary purpose. The Dunstaffnage Marine Laboratory (DML) has been involved in such a project since 1995. Through funding from industrial and local enterprise interests, it is intended to deploy the largest artificial reef complex in Europe, prior to the year 2000, in the north Argyll area. This project is unique in that the primary reason for developing the reef is scientific research.

The proposed reef will initially consist of 24 separate reef modules. The intention of the multi-unit reef complex is to incorporate a number of design and environment variables, which will examine the effect on reef performance of factors such as block shape, reef design and depth. This experimental array presents a significant opportunity for the DML to develop and maintain an innovative and exciting reef-associated research programme.

The ability to vary block and reef design dictates many of the proposed research objectives. However, this variation must be viewed within a socio-economic context. Influencing many of the research objectives of this project is the consideration that artificial reefs could offer a significant opportunity to isolated, fishery-dependent, communities to develop and manage reef fisheries as co-operatives. Contained within these socio-economic aspects is the requirement to develop artificial reefs that are economic which necessitates the use of cost-effective materials. At present, there are considerable volumes of industrial aggregate by-products available at relatively low cost to the constructor, which, when combined with ash and cement can produce a block which is suitable for inclusion in artificial reefs. There are a number of considerations which need to be addressed regarding block manufacture including the balance between performance, environmental acceptability and cost {MacDonald, 1994 #32}.

The DML Waste Management Group is an Environmental Body established under the Landfill Tax Regulations 1996 (SI 1996 No. 1527). The major aim of the Waste Management Group is to establish methods of waste management, within the marine context, which give value-added use for that waste while minimising environmental impact.

Programme of Research

For the purposes of research planning, the overall scientific programme has been divided into two phases. Phase I concentrates mainly on research which is required to be undertaken prior to the reef being deployed. It is envisaged that Phase I will culminate with the construction of the reef complex and, as such, will have finite duration. Phase II will, initially, last 5 years following deployment. Further research phases will occur linked both with the continued development of the reef environment, but also incorporating elements of habitat manipulation and the addition of supplementary reef variables to designs which are well tested and understood. However, as many of the research objectives in future phases are dependent on results generated through Phases I and II, only these two initial research phases are considered here. This annex describes in detail the major areas of research that are proposed to be undertaken in the immediate future, which will coincide with periods of reef pre- and post-deployment.

Research Phase I: Pre-deployment studies

Pre-deployment research, frequently lacking in other scientific programmes, will allow the evaluation of the effect of the reef. This phase is of paramount importance to the overall value of the scientific programme.

(i) Reef block manufacture and design

The use of construction-grade concrete in artificial reef block manufacture for deployment on a commercial scale is economically non-viable. If a reef is to be large enough to be of use as a fishery enhancement device, then cheaper alternatives must be considered. Construction materials available to this project include large volumes of a very fine aggregate by-product and fly ash products. Preliminary studies have indicated that it is possible to make a block using these by-products mixed with cement and granite dust. The by-product is produced from an aggregate washing facility and consists of a very fine rock powder. The use of this by-product in concrete manufacture poses several technical problems which are influenced by the demands of the proposed scientific research. In addition, the inclusion of some listed heavy metals in fly ash is of concern within the context of an environmentally sensitive waste management programme.

Power station fly ash is an effective and affordable pozzolan in concrete manufacture, and its proposed inclusion in blocks for this reef is a logical utilisation route. However, fly ash contains a number of heavy metals which cannot be disposed of at sea in a bioavailable form. Inclusion within concrete blocks could prevent heavy metal contamination of the marine environment; other studies, unrelated to this research programme, have demonstrated negligible bioaccumulation of heavy metals from artificial reef blocks designed to maximise fly ash content (Collins et al. 1992; Collins and Jensen 1995). However, the analytical methodologies used in these studies have relatively poor levels of detection and resolution and the results may simply reflect this. There will almost certainly be some mobility of constituents within blocks and some transfer to the water column with concomitant bioaccumulation. The DML has the analytical facility (Induced Plasma Coupled Mass Spectrophotometer - IPCMS) to detect very low heavy metal concentrations. A systematic investigation of leaching and bioaccumulation rates under a variety of environmentally relevant situations will give an accurate, detailed description of the fate and behaviour of ash-derived heavy metals in the marine environment. If leaching is detected, it will be a requirement to research the effects of very low levels of metals to a diversity of selected species representative of different trophic or functional levels.

The effect of block complexity may be an important factor dictating reef performance. The hypothesis being tested is that increasing the surface area to volume ratio yields a more biologically productive reef, which, in turn, will be more productive in economic terms. Producing a complex block introduces technical problems to block manufacture; this aspect requires further research.

In summary, priority research includes that required to produce the strongest most cost-effective concrete block which supports complex shapes. Preliminary work in this area has already been carried out and has shown that a mix containing ca. 20% fly ash will be necessary to meet strength criteria. This research is continuing in collaboration with materials experts.

(ii) Reef design

In the initial reef complex two reef designs will be employed. As is discussed below, the actual intricacy of the reef designs is limited to some extent by the practical difficulties of remote deployment. The main research objective is to compare reef units with differing edge to unit volume ratios. Preliminary studies have suggested that reef productivity is higher the more contrasting the environment offered {Seaman, 1996 #25; Spanier, 1996 #24; Beck, 1995 #13}. The extent of the reef edge is thought to be an important factor, particularly for animals which utilise both hard and soft substrata, such as the lobster. To test this hypothesis, the two proposed reef designs will have similar volumes but differing lengths of reef-sediment interface.

Reef design will also incorporate models which predict optimum inter-block spaces using different block arrangements and size ratios. It is possible that rather than retaining a standard block size for each type of block and reef, it may be preferable to incorporate a number of blocks which have, for example, been broken in half. Different reef characteristics could be obtained by simply altering the proportions of whole to half blocks. If it is found to improve refuge provision, then the differing effects caused by manipulating whole to half block ratios will need to be predicted. Predictive models required by this programme are currently being developed by groups external to the DML and collaborative links are already established.

(iii) Reef deployment

There are a number of complications associated with the successful deployment of a reef which is both large, and intended for quite intricate scientific experimentation. Considerations include the accurate positioning of each reef unit, the accurate and reproducible deployment of the two reef designs (each reef sub-unit will be deployed in 5 loads, 400 tonnes each load), and the effects of actual deployment on individual block integrity. Essential to these factors is the behaviour of individual blocks as they sink through the water column and how the likely spread of blocks following surface deployment is affected by depth, current regimes and block design. A research project will be initiated with the object of establishing methods of deployment which are practical and cost-effective, but which will produce reef units of reproducible design and which minimise block damage.

The DML has contributed to the development of Differential Global Positioning Systems (D-GPS) which facilitates very accurate position fixing in the marine environment. This facility will assist in the accurate deployment of the reef modules.

(iv) Data Collation

This proposal is based on a programme of high quality scientific research. Integral to this ideal is the establishment of a series of biological, hydrographical, geochemical and socio-economic databases. The quality of the data collected through the pre-deployment phase will dictate the scientific integrity of much of the post-deployment research. Inevitably there will be the requirement to make pre- and post-deployment comparisons. Given below are summaries of the main areas of data collation which will be undertaken through the pre-deployment phase.

(a) Biological

One of the major questions related to the whole area of artificial reef research is whether the presence of a reef increases the total biomass and productivity of an area, or whether it simply acts as an aggregating feature which concentrates mobile species (Harmelin and Bellan-Santini 1996). One school of thought suggests that rather than increasing the fishery potential, a reef will concentrate exploitable resources and fishing effort in a finite region which can result in over-exploitation and a net decrease of stocks in the overall locality. This question has never been examined in a systematic fashion and is also central to a more fundamental understanding of the dynamics of natural populations of mobile macrofauna.

In order to establish the true effects of a reef deployment, a detailed programme of surveys over the proposed deployment site and adjacent natural reef areas will establish the levels of productivity occurring prior to the construction of the artificial reef. Also individuals of selected species will be tagged in order to identify any direct movement between natural and artificial reefs. A large-scale tagging programme should distinguish natural variations in population structure (abundance and distribution) over a variety of temporal scales (tidal, diel, seasonal and annual). Changes in population strength can also be detected using biological proxies. Work previously undertaken by this group has shown that indices of growth and reproductive potential can alter with relative population density {Sayer, 1995 #14}. Obtaining at least two years biological index data, in addition to existing data, will give sufficient baseline information from which annual trends can be eliminated, and post-deployment work can be based.

Biodiversity, and the modifiers of biodiversity, are areas of research which have recently attained high prominence. Research into biodiversity aims to elucidate the processes and factors which affect the structure of communities. To this end, the artificial reef project offers an unique opportunity to examine how communities develop over a running set of temporal scales. There are basically two ways in which organisms can come to be found on a structure. Either they settle there in the larval or post-larval phase and remain, or they migrate from another habitat. The deployment of settlement traps over the two years prior to deployment, and in the subsequent post-deployment years, will establish a record of the cocktail of organisms expected to settle, or actually settling, on the newly deployed reef. Subsequent surveys will determine how the communities develop from this initial settlement, and how they subsequently alter with time. The reef unit variables should also detect effects of reef structure and parameters associated with water depth, on community development. The biodiversity theme is one which will be incorporated into future NERC science budget-funded research.

(b) Hydrographical

The local hydrography will affect site selection as it will influence the performance of the reef. If the reef is constructed in an area with negligible current then excess sedimentation could occur resulting in smothering. Conversely, if the reef is sited in strong currents the blocks may be shifted leading to destabilisation and loss of structure. Past sedimentation rates and, by inference, local hydrography, can be determined through radionuclide determination and lead isotope analysis. However, reef deployment may effect the hydrography through the alteration of current profiles. This could have a detrimental effect on reef performance if it results in enhanced deposition rates. Although this may not be a problem at the selected site, data obtained from pre- and post-deployment current profile surveys could be used to construct a model to predict changes in sedimentation pattern which occurs as a result of reef construction. This type of model may assist in the placement of new artificial reefs.

The proposed construction site is close to the exit of a large catchment fjordic system. Such an area may be vulnerable to large and rapid fluctuations in temperature and salinity, the scale of which will be largely dependent on depth. As is described above, reef construction may alter current profiles. This may result in changes in temperature and salinity profiles over a range of temporal scales which will be detected by comparing pre- and post-deployment data sets. Current, temperature and salinity measuring buoys will be stationed within the reef complex area, and at a range of depths, in order to build up a comprehensive profile of hydrographical fluctuations. Excessive low salinity influences may significantly affect community development on the shallower reef units, and these profiles will be measured and tested in order to eliminate (or otherwise) salinity from the depth variant in the reef matrix.

A surface meteorological station will be established at the proposed reef site and will monitor wind strengths and directions. These data will be used to predict likely wave extremes which may affect the reef structure.

(c) Benthic surveys
To establish the impact on the benthic communities following reef deployment there will be a requirement to obtain detailed profiles of the benthos {Badalamenti, 1996 #34}. A network of sample stations will be established at the proposed site and sampled at regular intervals to provide assessments of seasonal stability. The survey sites will be retained during and after the period of deployment in order to estimate the effects of disturbance.

(d) Geochemical
If heavy metals are leached from the deployed blocks, transport through sediments may be accelerated by bioturbation. Measuring baseline metal levels in the benthos, and the flora and fauna inhabiting the benthos, will be of use when attempting to detect metal fluxes influenced by the reef. Heavy metals may also be identified in sediment pore waters, and so baseline surveys will be required to obtain information against which comparisons can be made.

(e) Socio-economic
One of the main reasons for undertaking the proposed artificial reef research is to establish the value of similar deployments to fishery-dependent communities {Simard, 1996 #22}. Much existing socio-economic evaluation has been based on extrapolation from small-scale reef constructions. The proposed study will be significantly larger than any previous deployment, and will be capable of testing many of the assumptions made when extrapolating. The study will also yield a comprehensive cost summary for the project as a whole, which will give actual economic data for the models previously employed.

There is existing evidence to suggest that artificial reefs act to enhance fisheries based on wild-supply species. Whether this enhancement is an effect of aggregation or production is another aspect of the proposed research programme (see above). The ability to utilise the reef to establish a community-led fishery based on the principal of ranching has only been approached on a theoretical basis. This opportunity would be used to examine a ranching project, with the lobster as the selected species. In a theoretical examination of artificial reefs as sites for fishery development, (Whitmarsh et al. 1995) concluded that lobster ranching would be economically feasible on large reefs. However, that study was mainly based on data collected on a 50 tonne experimental reef. The proposed reef deployment would allow for an assessment to be made using actual data.

Post-deployment studies
Most of the post-deployment research compares measured data against pre-deployment baseline data. The rationale justifying the reason for undertaking much of the research is the same for both pre- and post-deployment studies and is not repeated here.

The timescale for the post-deployment research is not finite, although for strategic reasons, a nominal period of five years is given. Once deployed the reef will remain for perpetuity, and it is intended to collate information based on the main project topics outlined here for much longer than the initial five-year period. However, as is stated above, many of the research objectives may alter with time, and so Phase II is limited in its duration.

(a) Reef performance
Following the deployment of the reef, its stability will be monitored over time. There are differing elements of stability. Although the site has been selected in order to provide relatively soft sediments able to sustain a heavy top-load, there is always the possibility that some of the reef units may sink further into the bottom than others. Sinking rates may be exacerbated through bioturbation, or simulated through sedimentation. A number of measuring poles will be inserted close to the reef units to record sinking, bioturbation and/or smothering effects. Stability may also refer to the structural integrity of the reef units. It will be of importance to evaluate how, or if, the units retain their height and shape over time measured against a range of environmental variables, in particular depth (and by inference wave effects) and current profiles.

(b) Block performance
Individual block performance will be assessed over time, within the range of applied experimental parameters. These will be depth of deployment (wave action, temperature/salinity influences), block design, reef design, and oxic levels. It could also be anticipated that if the type or rate of colonisation differ within the experimental matrix, then this may also have an effect of block performance. Much of the proposed research outlined here will be based on actual field measurements which, in turn, will influence laboratory-based research projects.

Measuring metal leaching rates from the blocks will be in accordance with the leaching studies proposed for the pre-deployment phase. Samples from the proximate water column, benthos and sediment pore water will be analysed over a range of temporal scales. In addition, it is proposed to periodically take cores from the blocks to examine if metals are being lost (or possibly accumulated) along the block gradient. Attention will be focused on the block-water interface the location of which is determined by the extent of seawater penetration into the block. Associated with the leaching studies is an investigation of possible bioaccumulation of metals in organisms associated with the reef structure. Laboratory-based studies will identify organisms which bioaccumulate heavy metals in order to focus the field sampling programme.

Block strength may increase or deteriorate with prolonged marine deployment and will be the subject of investigation. Biological concretion is a possible modifying factor; this aspect will be researched by the periodic removal and strength testing of selected blocks.

(c) Socio-economic
Collation of all associated costs and benefits arising from this deployment will continue in order to provide actual data for models estimating the potential for future commercial-scale reefs. The following will be undertaken:

- an economic evaluation of artificial reefs for mariculture;
- the identification of user group perceptions and demands for artificial habitat requirement;
- the formulation of a bioeconomic model of reef-based fisheries;
- an analysis of the scale, design and efficiency of artificial reef systems;

- a comparative legal analysis of the problems regarding artificial reef use in Europe;
- determining the role of artificial reefs in maintaining social infrastructure.

On the west coast of Scotland the potential for ranching lobsters, using the easily definable physical limits of artificial reefs to control regulation, has raised the real possibility of fisheries managed for the benefit of fishery-dependant coastal communities. The feasibility of lobster ranching will be examined on the proposed reef through collaboration with the local fishermen's association. Once the reef biota has developed sufficiently, the reef will be seeded with juvenile lobsters (the technology for juvenile lobster production is well advanced and commercially available). Frequent surveying and capture/release techniques will be used to determine rates of growth and survival. When the animals are at a marketable size then a managed fishing programme will be initiated. An economic model will be developed which will allow for variations in a number of associated variables, and will be used to assess the feasibility of artificial reefs being developed purely for commercial purposes.

(d) Biological studies

One aspect of artificial reef research which has commanded much attention, is that of reef colonisation. This consists of recording the arrival and/or settlement of organisms on the reef. Comparisons will be made between the colonisation of the reef and the numbers of particular species landing on the reef as planktonic fallout. This will provide information relating to the mechanistic processes of community structure, development and maintenance. Data from work of this type will have direct relevance to many aspects of biodiversity research. Once community processes are understood, the artificial nature of the habitat would allow for selected modifications or disturbances to the biotic or abiotic habitats to assess the consequences of change. Artificial reef colonisation has previously only provided information on settlement or arrival on the external or visible areas of the reef. Within the deployment of the proposed reef complex, it is intended to construct tunnels in some of the reef units into which infra-red sensitive cameras (with appropriate illumination) can be inserted. This will provide information relating to non-visible colonisation and allow a detailed assessment of temporal variation in habitat utilisation of selected species. The study of internal reef colonisation and animal behaviour in that environment is a unique element to the study.

The subject of whether the reef aggregates mobile macro-faunal species, or results in positive production, will be examined primarily through comparisons with information collected during the pre-deployment phase. Surveys of both the reef units and the adjacent natural reefs will record numerical changes or actual movements of tagged animals, and analysis of biological indices may give indirect evidence to support changes in relative population abundance. The mobility between reef units, or their fidelity for particular environments/refuges, will be examined in a range of mobile animals using high resolution sonar tags.

A programme designed to assess the possible impact to benthic communities will continue throughout the duration of the second research phase, or until no significant indicators of change persist.

(e) Hydrography

Hydrographical data collection initiated in the pre-deployment phase will continue post-deployment in order to detect changes caused by the reef. Analysis will have to continue for at least three years post-deployment so as to identify annual variations. Data will also be collated from control sites identified in the pre-deployment studies located away from the deployment area. As in the pre-deployment studies information on current, temperature and salinity profiles will be recorded.

(f) Geochemistry

Accepting that there may be contamination attributable to some block inclusions, the reef provides an essentially pristine habitat about which it is known precisely when colonisation was initiated. This contrasts with natural reefs where, although there may be inputs of newly settling organisms, the effects of existing flora and fauna cannot easily be subtracted. Once leaching effects have been quantified, these can be deleted from contamination profiles which could delineate cumulative impacts of anthropogenic influence.

ANNEX 2.

The Waste Management Group Constitution

The Waste Management Group.

I. The name of the group is the "Waste Management Group" established on the 20th August 1997. It remains part of the Dunstaffnage Marine Laboratory, a component institute of the Centre for Coastal and Marine Science.

II. The objects of the group are:-

(a) To promote research and development into waste management practices with the aim of encouraging more sustainable use of waste materials. Results of research will be published in scientific journals and be freely available.

(b) To promote the re-use and recycling of waste materials and to find alternative and beneficial uses for such materials.

III. True accounts shall be kept of the sums of money received and expended by the group. An annual examination of the accounts of the group shall be undertaken by qualified auditors.

IV. The Waste Management Group is a non-profit distributing body. All funding will be used for the furtherance of the objectives of the group.

Articles of the Group

I. Preliminary

The Waste Management Group shall be governed by the regulations contained in these articles. In concordance with provisions made herein articles may be subject to amendments, alterations, additions or be rescinded.

II. Interpretation

The "Laboratory" is the Dunstaffnage Marine Laboratory incorporating the Scottish Association for Marine Science.
The "director" is the director of the Laboratory or his official deputy.
The "group" is the waste management group.
The "project" is any distinct area of research being undertaken by any members of the group.
The "committee" is the waste management group committee.
The "funding proposal" is the proposal to undertake research based at the Laboratory and submitted by an employee of the laboratory to the landfill site operator.
The "regulatory authority" is the Environmental Trust Scheme Regulatory Body.

III. The Committee

1. A member from each project within the laboratory which receives funding in accordance with the objects of the waste management group will be able to sit on the committee.
2. The committee will meet by mutual consent to discuss matters relating to the management of the group. The management of the group will be decided by the committee by common consent. One member will be nominated as the individual responsible for maintaining contact with the regulatory authority.
3. The director will appoint an external auditor to ensure that any funding received is used as outlined in the funding proposal. The auditor is obliged to contact the regulatory body to report any failure to comply with the regulations as stipulated in section 53 of the Finance Act, 1996 regulations 30 to 36 inclusive.
4. The committee is able to change the objects and articles of the group by common consent.