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Ocean & Coastal Management 44 (2001) 241–259

www.elsevier.com/locate/ocecoaman

Ocean &
Coastal
Management

Artificial reefs: a review of their design, application, management and performance

Mark Baine*

*Department of Civil and Offshore Engineering, International Centre for Island Technology,
Heriot-Watt University, Old Academy, Back Road, Stromness, Orkney Islands KW16 3AW, UK*

Abstract

A comprehensive literature review is undertaken of global artificial reefs, their design, application and management. The majority of papers are linked to North American research, reefs constructed from concrete and to the general theme of fisheries ecology and management. Within the review, the main area highlighted for consideration in future research and management is the design and complexity of artificial reefs. A more limited case study review identifies monitoring and management as crucial factors, noting a significant lack of information relating to ownership, liability, regulation, user conflict, environmental assessment and long-term management goals. An assessment of reef performance indicates that only 50% of the case studies meet their objectives, the remainder having no, little or limited success. Questions are therefore raised regarding their value. It is concluded that although artificial reefs do have the potential to fulfil the many objectives for which they are promoted, their success will ultimately reflect the quality of prior planning and ongoing management that is afforded them. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

The European Artificial Reef Research Network (EARRN) defines an artificial reef as a submerged structure placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef [1]. Their use as a tool in coastal management has many general purposes including deployment in Japan to increase fisheries yield and production [2], recreational diving in the United States [3], and the prevention of trawling in Europe [4]. Artificial reef reviews do exist [5] although varying in their focus and objectivity.

*Tel.: +44-1856-850-605; fax: +44-1856-851-349.

E-mail address: ioemspb@icit.civ.hw.ac.uk (M. Baine).

This paper aims firstly to present the findings of a comprehensive investigation of the global use of artificial reefs, providing the modern coastal manager with a concise, readily accessible review of their design, application and management. Secondly, the paper aims to evaluate the degree to which artificial reefs meet the objectives for which they were placed.

The main literature review undertaken for this study comprises 6 volumes of published papers on global artificial reef research. These include two special editions of the *Bulletin of Marine Science* [6,7], two volumes comprising the proceedings of ECOSSET '95, the International Conference on Ecological System Enhancement Technology for Aquatic Environments [8], the proceedings of the 1st EARRN Conference [9] and the proceedings of the 30th European Marine Biology Symposium [10].

In total, this study reviewed 249 abstracts from these collections of artificial reef papers, producing a brief summary of their themes (coverage and application where appropriate), material employed, highlighted design and/or management issues, and country of origin or geographical spread. The results of this review are based solely on information in abstracts and are not intended to be full appraisals of the content of papers. Highlighted design and/or management issues, therefore, may be selective and should not be considered as definitive in terms of the authors' intentions or the papers' coverage.

It should also be noted that the vast majority of papers reviewed presents results from ecological research and is not specific in terms of presenting the history and purpose of individual artificial reefs. It is not surprising, therefore, that many papers within this review will relate to the same artificial reef, repeating specific research or covering related research initiatives. Many of the papers examined also cover reefs constructed from a variety of materials or individually present findings on a number of themes such as fisheries and waste disposal.

In addition to the above abstract review, this study sought to examine in greater detail a representative sample of global artificial reef initiatives. This more detailed appraisal sought to present information on specific artificial reefs, their material and design, purpose, monitoring, management and performance in relation to their purpose. To this end, the case study review was limited in numbers by its intended scope (30). For example, many papers only present information on specific research objectives and do not necessarily cover all of the above parameters in a concise format. The case studies, therefore, were selected primarily according to the breadth and quality of information available for review and analysis. The secondary selection criteria was to cover the range of reef applications identified by the general literature, whilst also covering an adequate spread of materials and designs. To this end, some papers outside of the above main literature review were also selected for examination.

In reviewing these case studies the author has also provided an indication of the reef's performance in relation to its given purpose for placement (or research objective). This involved the creation of a Reef Performance Scale. It must be stressed that this exercise is not intended to be absolute in its

assessment, but is merely based on the information provided by specific papers and reflects this author’s interpretation of reported results and quality of management.

2. Literature review

Despite the artificial reef definition provided in the previous section, historically they have also incorporated fish aggregating (or attraction) devices (FADs) which normally consist of mid-water structures, anchored to the seabed, aimed at attracting pelagic fish stocks [11,12]. Steering away from validations, however, this review has examined 249 abstracts from a collection of 6 volumes of artificial reef proceedings. These abstracts have been analysed in terms of geographical focus, artificial reef material, paper coverage and highlighted design and management features.

2.1. Geographical distribution

Fig. 1 summarises the geographical coverage of the literature review. As can be seen, the majority of papers are concerned with North American artificial reefs (38%) dominated by the United States of America. Europe comprises 29% of the review, although it should be noted that two of the volumes reviewed were dedicated to European research. Published literature on European artificial reefs has become more accessible, primarily through the formation of EARRN. Italy is the leading country in Europe for artificial reef research. Statistically, the UK appears to have a strong research pedigree, however, this is mainly related to a high publication rate



Fig. 1. Geographical spread of reviewed abstracts.

with respect to the Poole Bay artificial reef project and theoretical discourse and reviews.

Although widely acknowledged as the leading country in artificial reef research, particularly in terms of engineering design, only 29 papers (12% of the review) represent Japan. Africa, Australia, Central America and South America do not appear to be prolific exponents of artificial reefs although this may be due merely to a lack of published material.

2.2. Material

Table 1 provides a breakdown of the types of material used in artificial reef construction. It should be noted that as a number of artificial reefs reviewed in this study were composed of a variety of materials, the total figure is greater than 249. By far, the most favoured reef material is concrete including cubes, blocks and pipes. Concrete has also been used in combination with other reef materials such as vessels, quarry rock, tyres and plastic. Natural stone and rock is the next favoured material. Offshore platforms and FADs, the latter constructed from wide-ranging materials including canvas, plastic, anchor blocks, etc., are the next common materials, the platform studies concentrated in the Gulf of Mexico. The wide range of remaining materials used confirms the varied approach to the creation of artificial reefs. Material includes train cars, dock gates, mineral accretion, trees and branches, artificial seaweed and queen conch shells.

Table 1
Types of material used for artificial reef construction

Material	Number of citations
Concrete	79
Rock, stone, boulders, gravel, etc.	29
FADs	17
Offshore platforms	16
Tyres	15
Stabilised ash waste, harbour mud	14
Plastic, PVC, etc.	12
Vessels, barges, shipwrecks	11
Wood, trees, etc.	11
Breakwaters, coastal structures	12
Steel, metal	10
Rope, netting	9
Automobiles, train cars	6
Unspecified mix of materials	6
Review of wide range of materials	13
Other materials	18
Unspecified	31
Total	309

2.3. Themes

Table 2 provides a guide to the coverage of the reviewed papers. It should be noted that the figure in brackets represents the number of papers where this particular theme is only a portion of the coverage of the paper. For example, 10 papers have covered sport fishing, however, one is multi-thematic and its main focus is recorded elsewhere. Similarly, although a total of 108 references are made to the general theme of “fisheries ecology and management”, up to 18 of these are secondary themes and may have been recorded as focussed themes elsewhere within this general theme. There is thus the potential for slight repetition when examining the total figures for each general theme.

From Table 2 it can be seen that “fisheries ecology and management” is a central theme for artificial reef studies, covered by over 36% of the papers reviewed. Of these, nearly half are concerned with fish attraction, fish assemblages, their distribution and abundance. Fisheries production, enhancement and improvement along with fish ecology and behaviour are also well-documented themes. In terms of general themes, the next major sector is “design and monitoring” covered by over 18% of the reviewed papers. The majority of these reflect the need for adequate monitoring and sampling methodologies.

Over 16% of the papers covered “general reviews and theory”, the majority of these related to geographical reviews and discussions on issues of planning and management. Over 12% and 10% of the papers related to “general ecology” and “habitat protection and mitigation”, respectively. Epifaunal studies and mitigation for habitat loss are the main foci of research for these general themes.

Other general themes covered by papers include “mariculture”, “sport diving”, “waste disposal” (mainly related to coal ash) and “coastal protection and development”.

Table 3 presents themes covered by different papers in terms of the material used as artificial reefs. One should again note that a paper may have covered both anti-trawling and improvement of fishing; or fish assemblages and fisheries enhancement, etc. and may thus be cited more than once. A particular reef from a paper review may also be composed of two or more materials. The coverage of this paper will therefore be documented for each material, any given paper thus being cited more than once. As can be seen concrete reefs have been associated with a variety of themes, most notably related to fish attraction, assemblages, distribution and abundance and, general ecology and epifaunal studies. Again, rock and similar material is associated with a variety of themes. FADs, on the other hand are mainly associated with fish attraction and fisheries related themes. Although studies have been carried out on reefs constructed from offshore platforms, the majority of the review concentrates on feasibility and management issues. Tyre reefs have mainly been associated with fisheries; vessels with fisheries, sport angling and diving; stabilised ash waste with waste disposal issues and epifaunal studies; breakwaters with habitat provision and design issues; wood with artisanal fishing; with both steel and plastic reefs relating to a variety of themes.

Table 2
Themes covered by the reviewed papers

General theme	Focused themes	Number of papers
General reviews and theory	Geographical reviews	11(6)
	General planning, development and management	10
	Economics and legislation	6
	Materials, design, feasibility studies	6
	Habitats and ecosystems	3
	Environmental effects and modelling	3
	Social issues, users and conflict resolution	2(1)
	Total	41(7)
Fisheries ecology and management	Fish attraction, assemblages, distribution and abundance	40(2)
	Fisheries production, enhancement, improvement of fishing	19(10)
	Fish ecology and behaviour, sheltering, feeding and spawning	16(5)
	Sport fishing	9(1)
	Juvenile fish recruitment and abundance	6
	Total	90(18)
General ecology	Epifaunal studies	11(4)
	Species richness and abundance	8
	Algae and kelp coverage	5(1)
	Colonisation	4(2)
	Invertebrates/mussels	3
Total	31(7)	
Design and monitoring	Baseline surveys and sampling methodologies	19(1)
	Evaluation, testing, experimentation and life expectancy of materials	15
	Design features and siting, provision of refuges, juvenile protection	11(1)
	Stability and structural integrity	(2)
	Total	45(4)
Habitat protection and mitigation	Mitigation for habitat loss	9
	Habitat for seaweed and kelp	8(1)
	Anti-trawling and prevention of damage to the seabed	5
	Water quality	2
	Freshwater aspects	1
	Review	(1)
Total	25(2)	

Table 2 (continued)

General theme	Focused themes		Number of papers
Sport diving	Sport diving		1(4)
		Total	1(4)
Mariculture	Shellfish culture and provision of nursery areas Seaweed cultivation		7(1)
			2
		Total	9(1)
Waste disposal	Waste disposal		5(1)
		Total	5(1)
Coastal protection and development	Breakwaters and coastal protection Ports and coastal structures		1(1)
			1
		Total	2(1)
Total			249

Table 4 provides a breakdown of issues identified within the paper abstracts. These were highlighted as potentially important factors in design and management. Again, the figure in brackets represents the number of papers that raised a number of issues, of which the primary one is recorded elsewhere in the table. As can be seen 76 papers did not highlight any significant issue or factor, these mainly being descriptive in nature, reviews or dedicated to experimental methodology.

The main areas highlighted relate to the artificial reef itself and design features. For example, 36 papers (14%) noted the importance of design complexity, the configuration of the reef, its size, volume and area. The provision of shelter through refuges and crevices was highlighted as important by a number of papers (6%), particularly in relation to juveniles and shellfish. Other major design factors include the structural integrity and stability of the artificial reefs and the type of material used. Other aspects deemed important in targeting fish species include the provision of void space, bottom relief, height and shading.

Very much integrated with the reef and its design is the site where the reef is to be placed and local environmental conditions. 40 papers (16%) cited the importance of local habitat and ecological characteristics such as recruitment, target species, colonisation, fish behaviour, sediment type and biodiversity. Other factors often cited as important include currents and wave action, and other hydrographic parameters such as temperature, depth and water quality.

Aspects of planning and management were also raised, general planning and management being highlighted in 19 papers (8%). Other more specific factors include aspects of socio-economics, performance evaluation and monitoring.

In terms of deployment, 13 papers (5%) highlighted the importance of the location. Other factors include seasonality and temporal considerations.

Table 3
Number of papers relating specific categories of artificial reef construction material to a general theme

Theme	Construction materials										
	Concrete	Rock, etc.	FADs	Offshore platforms	Tyres	Vessels, etc.	Plastic, etc.	Ash waste, etc.	Break- waters	Wood, etc.	Steel, etc.
Fish attraction and distribution, etc.	21	5	5	3	3	1	3		2	3	1
Fish ecology and behaviour, etc.	6	3	2		3			1			
Juvenile fish recruitment, shelter etc.	5	3	2				3				
Fisheries enhancement (incl. angling)	14	5	6	3	6	8	1	2	1	5	2
Colonisation, epifaunal studies, etc.	19	4		2	2	2	2	7		2	3
Coastal and habitat protection, habitat provision	9	1				1			4		
Habitat rehabilitation and mitigation	6	5					1				2
Sport diving	1			2		4	1				1
Survey methodology, design evaluation, etc.	10	4	1	1	3		2		4		2
Seaweed and shellfish cultivation, aquaculture	2									2	1
Waste disposal issues								6			
Reviews and theoretical discourse	2	1	2	8	1	1		1	2	1	

Table 4
Crucial factors and issues highlighted by the reviewed papers

General issue	Specific issue/factor	Number of papers
Aspects of planning and management	General planning and management	15(4)
	Socio-economics	1(8)
	Efficiency and evaluation	4(3)
	Monitoring and standardisation of approaches	6(1)
	Permits, legislation and liability	1(5)
	Social acceptance and conflict resolution	2(4)
	Research and modelling	(3)
	Cost	2
	Property and harvesting rights	2
	Life expectancy	1
	Education	1
	Safety	1
	Use	1
	Total	37(28)
Deployment	Location, siting, exclusion mapping	9(4)
	Seasonality, temporal considerations	5(4)
	Engineering aspects, marking, mooring, etc.	3(4)
	Environmental impact	2
	Total	19(11)
Environmental and site conditions	Local habitat and ecological characteristics	23(17)
	Currents and wave action (scouring)	8(4)
	Temperature, turbidity, siltation, salinity, water quality	6(4)
	Depth	5(3)
	Natural reefs and their proximity	3(2)
	Pollution	(2)
	Sediment type	1
	Climate	1
	Total	47(32)
The reef and its design	Design complexity, configuration, size, volume and area	28(8)
	Provision of crevices, refuges and shelter	12(2)
	Structural integrity, stability and durability	8(4)
	Structural material and density	4(3)
	Surface area and texture	3(1)
	Bottom relief	3
	Void space	2(1)
	Horizontal surfaces	2(1)
	Height and vertical relief	1(2)
	Shading	1(1)
	Reef age	(1)
	Total	64(24)

(continued on next page)

Table 4 (continued)

General issue	Specific issue/factor	Number of papers
Fisheries	Fishing pressure, exploitation, illegal fishing	4(1)
	Production vs aggregation	2(1)
	Total	6(2)
No focus	No specifically credited or highlighted features	76
Total		249

In terms of fisheries, only 5 papers (2%) raised the importance of fishing pressure, exploitation and illegal fishing.

3. Case studies

Further to the literature review, this study identified 30 case studies [13–42] for more detailed examination of reef site, design features, purpose, environmental conditions, monitoring and management, and performance. An integral part of this review was an assessment of the reef's performance in relation to its given purpose for placement (or research objective). A "Reef Performance Scale" was developed for this assessment and is presented in Table 5. As stressed above, this exercise is not intended to be absolute in its assessment, but is merely based on the information provided by specific papers and reflects the author's interpretation of reported results and quality of management.

3.1. Reef purpose and design

This case study review has captured a variety of artificial reef functions and designs. Fig. 2 relates the referenced case studies to reef activity. Reef design is variable in terms of material used, area covered, volume and complexity. The case studies have attempted to reflect the use of material as identified in the main literature review (see Table 1). Fig. 3 relates the referenced case studies to reef material. The concrete and cement reefs include varying designs such as basic blocks, pipes, cube modules and pyramid arrangements. The combination reefs include boats and concrete, fibre reinforced plastic and concrete, and tyres and concrete. The extensive combination reef incorporates vessels, concrete, fibre reinforced plastic and aircraft.

Design and purpose in terms of case study coverage are related to each other in Table 6.

Table 5
Reef performance scale in terms of its objectives

Scale	Reef performance
−3	The reef has failed in its objectives and has negatively impacted on the local environment or sea users. Research reefs that have failed through poor monitoring and management and yield no useful results.
−2	The reef has failed in its objectives but has no discernible negative impact on the local environment or sea users. Research reefs that have produced no useful data, although this may be as a result of external factors.
−1	The reef has failed in its objectives but exhibits other beneficial effects in terms of the local environment or sea users. Research reefs that have produced results that are questionable in their interpretation.
0	The reef’s performance in terms of its objectives is inconclusive. Both negative and positive aspects of its creation are identifiable but the overall success of the reef is indeterminable. Management and/or design of the reef are flawed. Published material is unclear and/or confusing. Research reefs providing inconclusive data.
+1	The reef has only succeeded in meeting its objectives with limited success. Other beneficial effects are recognisable. Design features or management measures are flawed and require review in order to increase reef success. Research reefs that have provided data of limited use for the assessment of reef performance and management.
+2	The reef has succeeded in meeting its objectives in part. Benefits to the local environment or sea users are realised by the reef’s creation. Minor changes to design or management may be warranted but are not critical. Research reefs that have provided useful data for the assessment of localised reef performance and management.
+3	The reef has successfully met all of its objectives. The design features and management of the reef do not require change. Research reefs that have provided extensive and accurate data useful for the general assessment of reef performance and management.

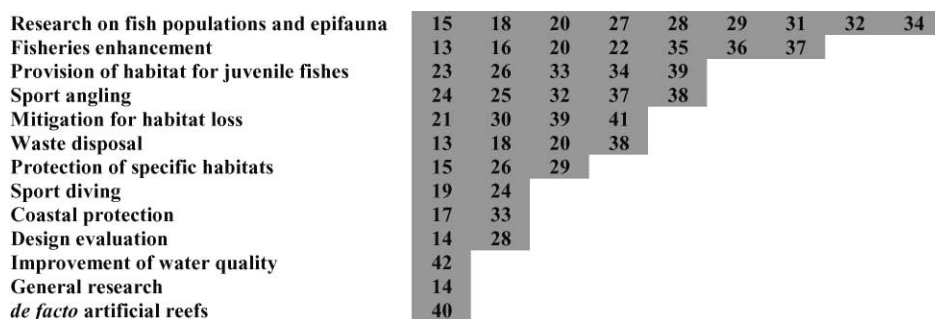


Fig. 2. Referenced case studies in relation to activity.

3.2. Achievement of reef objectives

The case studies have adopted many different approaches to monitoring and management. When examining monitoring in general or as a means of determining the performance of the reef in terms of meeting its objectives, the case studies range from poor to excellent. Many studies have employed a wide range of methodologies

Concrete and cement	15	16	21	22	25	26	27	31	36	39	41
Rock	14	17	18	30	33						
Combination reefs	29	34	37								
Stabilised ash blocks	13	20									
Offshore platforms	32	38									
Tyres	24	35									
Plastic, rope and netting	23	42									
Vessels	40										
FADs	28										
Extensive combination reef	19										

Fig. 3. Referenced case studies in relation to reef material.

including visual censusing, still and video photography, fishing surveys or more specific techniques such as acoustics, tagging and telemetry [13,15,22,39]. Other reefs [26,29,31,33,36] employ simple but effective monitoring programmes. Others were piecemeal in their approach and seemingly had little continuity or regularity, or indeed have been discontinued [16,21,23,32,34,40] although limiting factors such as climate may have affected the methodological approach. Despite the limited monitoring approach in some instances, these reefs in general provide information to allow some form of assessment of performance.

Another point to highlight includes the occasional lack of information on fishing activity in the vicinity of reefs and their potential influence on results, particularly for those studies assessing fish populations [16,20,22,25].

In terms of general management, there is a significant lack of information on such issues as ownership, liability, regulation, user conflict, environmental assessment and other long-term management needs. In many cases, this is most probably due to the selective focus of the papers. The main reference to long-term management is the Louisiana Artificial Reef Development Programme, a proactive multi-disciplinary approach to the maintenance of hard bottom habitat [32] in the Gulf of Mexico, although one case study [30] also refers to the development of set procedures such as the “habitat evaluation procedure” used to ascertain the change in epibenthic food availability for salmon. Another case study [38] closely examined the decision making process involved with reef development, siting and placement.

The following additional issues have been identified by the case study review in terms of management:

- storm damage and harsh environmental conditions [13,14,20,33,35,42];
- interaction with fishing gear [13,23];
- proper site location [14];
- design modification [17,22,23,28];
- cost effectiveness [38,41];
- user conflict [19,38];
- access [24];
- regulation of fishing effort [34,36];
- deployment method [37]; and
- reef usage [24,35,36,38].

Table 6
Case study references in relation to design and purpose

Purpose	Design								
	Concrete	Ash blocks	Rock	FADs	Offshore platforms	Tyres	Vessels	Plastic, rope, netting	Combinations
Waste		13,20	18		38				
Fisheries	16,22,36	13,20				35			37
Angling	25				32,38	24			37
Diving						24			19
Mitigation	21,39,41		30						
Water quality								42	
Habitat provision	26,39		33					23	34
Habitat protection	15,26								29
Coastal protection			17,33						
Ecological research	15,27,31	20	18	28	32				29,34
General research			14						
Design testing			14	28					
De facto							40		

Table 7
Allocation of reef performance scales to case study references

	Reef performance scale						
	–3	–2	–1	0	+1	+2	+3
Case study references		42		14,18,21, 22,23,35, 37	17,20,24, 30,34,40, 41	13,15,16, 19,25,26, 27,28,31, 32,33,36, 38	29,39
Total		1		7	7	13	2

Table 7 summarises the assignment of “Reef Performance Scales” to the 30 case studies based on the definitions supplied in Table 5. These are based on the information presented in the relevant paper. As can be seen, only two of the case studies [19,39] successfully met all of their objectives. These respective case studies refer to the use of vessels and concrete modules for the prevention of illegal trawling in the Mediterranean Sea, and the use of concrete reefs to provide habitat for spiny lobster populations in mitigation for a marina construction in Biscayne Bay, Florida. These are both practical initiatives that have yielded readily definable results in terms of effectiveness.

Although 20 of the case studies are weighted as +1/+2, this shows that many artificial reef initiatives do not meet their objectives in full, with only limited success, albeit significant success in certain cases. It seems appropriate in these instances that the studies would benefit from more detailed review and management procedures, although this is difficult in terms of planning for unexpected events. For research studies, the data produced on the whole will merely be of relevance in a localised context, with only general inferences possible in terms of examining artificial reefs in a wider geographical context. In the majority of instances, the interaction between local environmental conditions, local ecology and the specific reef design make for very unique systems, which may not be reproducible elsewhere.

The scale of “0” has been assigned to 7 of the case studies, mainly reflecting the inconclusive nature of the presentation of the reef and its performance, both in practical and research terms. This also reflects a lack of adequate monitoring and management plans. Although certain projects appear to have successfully met some of their objectives, e.g., disposal of excavated rock material [18], this is not fully discussed in terms of acceptability, impact of placement and the provision for future monitoring. Such projects are therefore awarded this scale as a means to demonstrate the need for more detailed investigation.

Only one reef has received the scale of –2, the examination of reefs as systems to absorb nutrients in the Baltic Sea [42]. This was a research project, which appeared to have been slightly overwhelmed by the highly eutrophic nature of the Baltic. In addition, another case study [35] was provided with an overall scale of “0”, reflecting

the presence of negative and positive aspects. The former mainly relates to the loss of a reef as a result of a hurricane. This if examined solely would undoubtedly be on the receiving end of a –3 scale point.

Inevitably one must question the value of artificial reefs that are at the most only meeting objectives with limited success (i.e. scale +1 and below). In terms of the case study review, this represents exactly half of the reefs examined. This again is difficult to address, for example, a reef which has appeared to have met its main objective of waste disposal [18], with seemingly little impact (although unpublished), may generally be viewed as successful even though it has not provided clear ecological benefits (which is the supposed output from the reef's creation). It is difficult to assess this reef without having more detailed information on the objectives behind the study, its cost and a comparative examination of the alternative disposal routes that were available.

4. Discussion

The preceding sections have set out the results of the literature review and case study analyses. They have examined the purpose and research themes of artificial reefs, their design, highlighted issues, monitoring, management and performance.

Some major points to mention include the variety of designs and uses available. This inevitably makes it very difficult to assess artificial reefs and their performance, relating this to a separate geographical area with different environmental conditions. Aspects of design, for example, in an artificial reef from the Mediterranean placed to target a certain species or fulfil a certain function (e.g., surface texture, material density), will not necessarily be primarily important in a North Sea context. Many factors such as the ecology and behaviour of the target species will be more influential to the success of any such venture. There are, however, general inferences in terms of design, such as the need for high-profile structures in the attraction of pelagic fish and the use of low profile, bottom reefs with extensive void space to attract mobile shellfish. Also in general terms, the information available is useful in examining the scope and requirements of artificial reef projects. We are presented with a multitude of factors, which need to be taken into consideration when examining the feasibility of placing an artificial reef for a given purpose. The planning and management of such projects, therefore, must be thorough. This is reflected by the figure of at least 15% of the reviewed abstracts covering aspects of planning and management.

A sample of 12 artificial reef managers was examined in a study [43] of the status of United States artificial reef programmes in relation to administration, budgeting, siting, promotion, education, evaluation, etc. Borne from this survey was the realisation that there is no single approach to addressing these aspects. Management systems were based on individual experiences with their own historical, social, economic and political factors. The study stressed the importance of management efficiency including rational siting, extensive consultation and adequate evaluation. A further study [44] expresses the importance of managers working closely with the

users. Indeed, there are many aspects of management worthy of individual extensive attention including socio-economics and economic evaluation [45,46], conflict analysis [47], siting [48] and design [49].

It is also necessary to raise the question of whether artificial reefs are the most appropriate solution to a problem [50]. It is important that any management solution to a problem, particularly one which incorporates the placement of artificial structures in the sea (perhaps more so in terms of the use of waste material), is shown to be the most effective long-term option. The profile of artificial reefs has recently come under closer scrutiny in terms of the acceptability of placing structures in the North-east Atlantic, with the production of OSPAR guidelines on artificial reefs in relation to living marine resources [51]. These guidelines stress the need of the following for the justification of an artificial reef project:

- environmental impact assessment;
- expected benefits;
- evaluation of alternative designs and placement methods; and
- provision for baseline studies.

Upon entering the construction and placement phase the guidelines advocate the use of inert materials (non-polluting through leaching, physical or chemical weathering and/or biological activity), while asserting that use should not be made of materials constituting wastes or whose disposal at sea is otherwise prohibited. In terms of design, issues surrounding durability, stability, decommissioning and spatial occupancy are also raised. Placement is also viewed in terms of other users, consultation, and aspects to be taken into consideration when siting the reef such as local environmental conditions. The guidelines further promote the initiation of baseline surveys, monitoring programmes and the clear specification of responsibility for management and liabilities.

In terms of performance evaluation, the limited case study review undertaken in this report has indicated an even spread of 15 examples with significant success or benefits noticeable in relation to their objectives and 15 examples either showing no, inconclusive or limited success. There are many factors to be taken into consideration including the specific foci of papers, the tendency for research to overshadow the main objectives for placement and the considerable lack of examples where adequate self-appraisal has been undertaken in terms of performance assessment. In general, therefore, one is not presented with all the relevant information necessary to make an informed and accurate assessment of the reef's success. This assessment, therefore, should not be viewed as absolute, merely as indicative. It is apparent, however, that much of the problems that have arisen in the case studies has related to general planning and management issues. These include siting, size, stability, cost, inadequate monitoring, unmanaged local use (most notably illegal fishing) and the influence of external climatic factors. It has been shown that artificial reefs do have the potential to fulfil the many objectives for which they are promoted, however, their success will ultimately reflect the quality of prior planning and ongoing management that is afforded them.

Acknowledgements

The author wishes to acknowledge the International Association of Oil and Gas Producers who funded this research.

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