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Trends in the sessile epibiotic biomass of an artificial reef

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Abstract

The Poole Bay Artificial Reef Project (PBAR) monitored the development of the first stabilised coal-waste artificial reef in the UK. This study documents the biomass of the sessile and mobile epibiota on this sublittoral reef, at approximately monthly intervals, following its deployment in June 1989. Biomass determinations were made to a constant weight at 80°C (dry weight) and 600°C (ash-free dry weight) following decalcification in 6% HCl. In general the epibiotic biomass from the concrete reef blocks was greater than that from the fly ash blocks.

The epibiotic biomass (gAFDWm^{-2}) on PBAR was compared to that found at other sites in the UK, both on stabilised coal-waste slabs and tiles and on a natural reef. The biomass of the sessile epibiota from the PBAR blocks compared well with that on a local natural reef, but was low compared with that found on free-standing slabs at the PBAR site and tiles in the littoral zone.

The epibiotic biomass on the bases of the free-standing slabs was found to be very much greater than that from both the tops of these slabs and from any facial orientation of the reef blocks.

Introduction

The structure and function of subtidal, hard substrate, sessile epibiotic communities cannot be studied easily by the normal quantitative methods applicable to infauna, owing to the predominance of colonial organisms which are often of a complex topography. Quantification of such a community is considered to be more appropriately examined using biomass measurements. However, as yet, no standard technique for the determination of epibiotic biomass exists. Of particular interest in artificial reef studies is the development, succession and seasonality of the epibiota, monitoring of which requires standardised biomass determination, techniques for which are discussed in more detail in [1].

The biomass of sublittoral epibiotic communities from artificial reefs had not been studied prior to [2] and only three studies have presented biomass data for sublittoral, artificial hard substrate epibiota in terms of ash-free dry weight (AFDW). Epibiotic biomass has been determined for shipwrecks [3] and artificial shores [4] on the Dutch coast of the North Sea and for non-decalcified, low temperature ashed samples from Tufnol panels in Langstone Harbour, UK [5].

Biomass values were reported for artificial reef epifauna in the Black Sea, without stating the method of determination [6]. Wet weight (WW) was reported for preserved organisms from artificial reefs in South Carolina and Georgia, USA, with respect to the age of the reefs [7]; for biomass comparisons between epifauna from a concrete reef and infauna from the adjacent seabed in Delaware, USA [8]; and for epibiota from fouling panels in South Carolina, USA [9]. Both WW and dry weight (DW) were measured for fouling organisms from test panels in Daya Bay, China [10].

The objectives of the present study were to attempt to quantify the sessile epibiotic community on the Poole Bay

artificial reef (PBAR) in terms of the biomass of its various components; to compare the epibiotic biomass found on stabilised coal-waste (fly ash) blocks with that on concrete blocks; to compare the biomass of the PBAR blocks with the epibiotic biomass found at other locations and depths; and to compare the colonisation potential of the different faces of a reef 'block'.

Materials and methods

Site description:

1. Poole Bay

The Poole Bay artificial reef was deployed in June 1989, at 50°39'72"N, 01°54'79"W in Dorset, UK (Fig. 1). PBAR experiences a tidal range of 1.7m on springs and 0.5m on neaps, with tidal current speeds from 0-0.75ms⁻¹. The reef was sited 2-3km from other rocky sites in Poole Bay, on a sandy seabed at a depth of 9.9-10.2m below Chart Datum. Underwater visibility at the reef site is generally between 0.5-2m, but can rise to a maximum of about 6m during the summer. Salinity and water temperature on the reef are about 34‰ and 7-16°C respectively.

The aim of the PBAR project was to investigate the viability of different coal waste mixes for artificial reef deployment. The reef consists of eight reef units placed in an area of about 15x35m. Each reef unit is conical and measures approximately 4m in diameter, and 1m in height and is made up of 200-250 blocks each of 40x20x20cm surface area. The reef complex consists of two concrete control reef units, and two reef units each of the three different coal waste mixes (Fig. 2).

Two further structures were placed on the seabed to the south of reef 7 on 16 May 1991. Each structure consisted of a 1m² frame of 5cm angle iron in the form of an 'open table'. The tops of these tables were divided into five double railed frames and were supported about 1m above the seabed by the table

legs. Surplus reef blocks were sawn into similar sized portions, of about 20x20x5cm, to form 'slabs' and 25 slabs were deployed on top of each frame, resting on the rails so that both the upper and lower faces of the slabs were exposed.

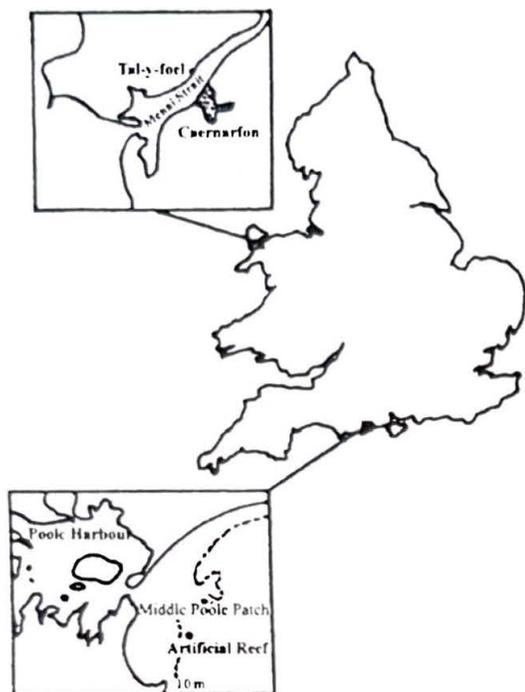


Fig. 1. Location of the Poole Bay Artificial Reef, Middle Poole Patch and Tal-y-foel study sites.

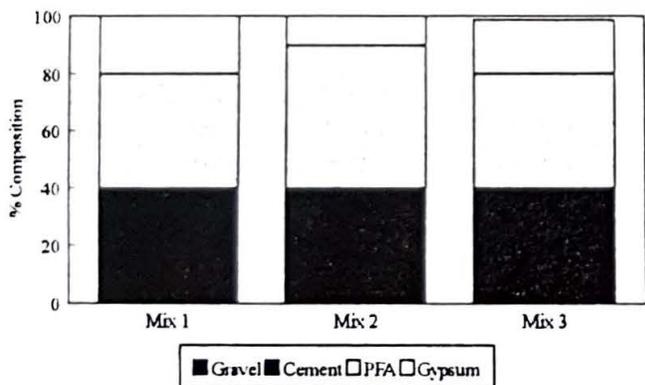


Fig. 2. Composition of the stabilised coal-waste artificial reef blocks, where PFA is pulverised fuel ash or 'fly ash' and FDG sludge is flue gas desulphurization sludge.

Middle Poole Patch (50°41'03"N, 01°53'35"W) is a Tertiary sandstone natural reef of about 1500 m² which is situated at a depth of 12m in Poole Bay (Fig. 1). This site was chosen as a comparative natural, hard surface area, which experienced similar biophysical conditions as the artificial reef and its epibiotic community.

2. Tal-y-foel

Tiles (15x15x5cm) consisting of the three different stabilised coal-waste mixes (Fig. 2) and concrete were also secured in angle iron racks housing 4 tiles and with wooden spacers between each tile. The tile racks were laid horizontally, and secured to the top of an oyster trestle at the MAFF Fisheries Laboratory (Conwy) site at Tal-y-foel, Anglesey, Wales (53°09'16"N, 04°15'13"W), in May 1989 (Fig. 1). The shelf-levels of the shell-fish racks were positioned at ELWS, and by virtue of their location on the beach, this left a clearance of about 1m between the position of the tile rack and the seabed.

Sample collection:

Blocks were randomly selected from the lower regions of two artificial reef units, one concrete and one fly ash, for the sampling dates: 9 April, 25 May, 12 July, 14 August, 27 September, 5 November 1990; 13 April, 16 May, 21 June, 23 July, 28 August, 5 October, 4 December 1991; and 26 February and 13 May 1992. Three slabs were collected from the slab frame on the same dates as for the blocks from June 1991 until May 1992, and also on 8 June 1992. Both blocks and slabs were placed within inner fine (1mm) and outer coarse (5mm) mesh bags, and raised to the surface using lifting bags. The fine net bags were used to retain any small mobile organisms that became detached from the blocks in transit, prior to their analysis in the laboratory.

Once lifted, the bagged blocks were placed in plastic boxes and covered with seawater to keep them wet during transportation. These were then stored overnight in seawater with aeration prior to examination in the laboratory.

Epibiota were also scraped *in situ* from five, 0.04m² slightly sloping, mainly horizontal areas of rock from Middle Poole Patch on 28 August 1991, and stored in 500ml pots with screw-on lids for transportation to the laboratory.

The epibiota from the tops and bases of the Tal-y-foel tiles were scraped off *in situ* on 12 August 1991, and transported to the laboratory in self-sealing plastic bags.

Biomass determination:

Sessile epibiota were scraped from each selected block, slab, tile and rock face in turn. The samples were then washed with freshwater in a 0.5mm sieve to remove traces of block material, silt and salt. The epibiotic community structure was investigated by considering five broad, morphologically similar taxa: erect organisms (algae, hydroids and erect bryozoans), ascidians, sponges, eggs and encrusting organisms (molluscs, barnacles, tube worms and encrusting bryozoans). Taxa were combined where physical separation was impossible.

The samples of each taxon on each block-face were air dried separately for about one hour, weighed, and then dried in crucibles in an oven at 80°C. When a constant dry

weight (DW) had been reached, usually within 12-48h, depending on the taxonomic composition of each sample, the dry block-face samples were amalgamated into taxa per block. A subsample of each taxon per block was weighed into a crucible, before being decalcified overnight by acid digestion in 6% Hydrochloric acid. After decalcification the subsamples were washed with distilled water, redried at 80°C, weighed to give the shell-free dry weight (SFDW) and then homogenised. Ash determinations were then made by placing the dry, decalcified and homogenised subsamples in a muffle furnace at 600°C, until a constant weight was achieved. This generally took about 4-6h.

The carbonate (or percentage loss in DW loss following decalcification) and ash determinations produced were then used to calculate the total SFDW and AFDW for each taxa from the original DW values, respectively [1]. This method utilised only a small fraction of the samples and thus decreased the length of time taken for their processing.

Results

Biomass determination of the PBAR block epibiota:

The biomass data, expressed as gAFDWm^{-2} for each sample and block type, for all taxa are presented in Fig. 3. These data points were produced by taking the total epibiotic biomass of a block (for the top, base, 2 sides and 2 ends) and dividing it by the total block surface area (0.4m^2). In general the total biomass of epibiota was greater on the concrete blocks than it was on the fly ash (Fig. 3), the only exceptions to this trend were for the July 1990 and May 1991 samples. The epibiotic biomass for the May 1992 concrete sample was at least three times greater than all of the values as a consequence of a similarly high encrusting organism biomass (gAFDWm^{-2}) (Fig. 3), whilst although not illustrated the absolute biomass value (gAFDWm^{-2}) for this taxon was higher on the concrete blocks.

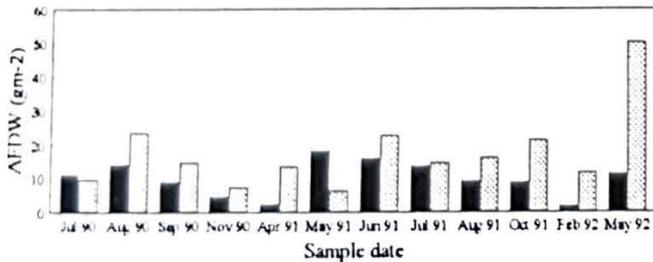


Fig. 3. Total ash-free dry weight (g m^{-2}) for epibiota from the fly ash (dark bars) and concrete (light bars) reef blocks from July 1990 until May 1992.

Biomass data in terms of the percentage contribution made by a taxon to the total biomass (gAFDWm^{-2}) for each sample and block type, for the taxa ascidians, sponges, eggs, erect and encrusting organisms, are presented in Fig. 4. There were no obvious trends in biomass with respect to block type for the erect organisms (Fig. 4), ascidians (Fig. 4), sponges (Fig. 4) or eggs (Fig. 4).

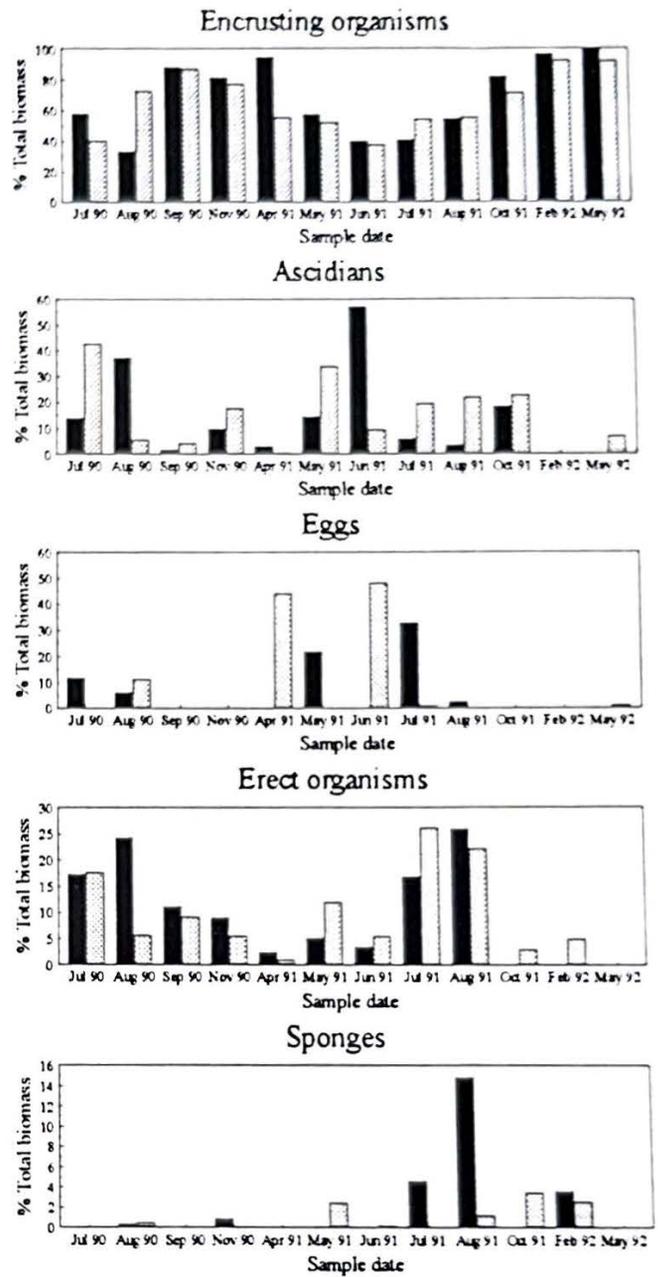


Fig. 4. The percentage contribution made by each taxon to the total sample biomass from the fly ash (dark bars) and concrete (light bars) reef blocks from July 1990 until May 1992.

There was evidence of a seasonal change in the total biomass (Fig. 3), with maximum values occurring during the summer months on both substrates. The encrusting organisms (Fig. 4) contributed as much as 100% of the total sample biomass and displayed high and low values during the winter and summer, respectively. The erect organisms and eggs (Fig. 4) displayed seasonal tendencies and contributed a maximum of 25% and up to 50% of the biomass in the summer months respectively, and less than 5% in the winter, whilst the sponges (Fig. 4) increased their contribution to the total biomass with time and were at a maximum level of about 15% on the fly ash blocks in August 1991. The percentage biomass contribution made by the ascidians (Fig. 4) fluctuated with time and was at its greatest at over 50% on the fly ash blocks in June 1991.

The biomass observed on the bases of the blocks was generally negligible as the blocks were either sitting on the seabed or partly resting on top of each other.

Gaps occur in the data (Fig. 4) for the ascidians, sponge, and erect organisms in samples from Oct 1991 onwards. These organisms were present during this period, but only in small quantities that were difficult to separate from the encrusting organisms and are thus included as part of this taxon.

Biomass determination of the PBAR slab epifauna:

The epibiotic biomass from the different slab faces is compared in Fig. 5. The bases of the slabs exhibited the greatest biomass, most of which resulted from the large amount of encrusting organisms present, except in February 1992 when ascidians were the main contributors to the biomass. The tops of the slabs with the exception of the August 1991 sample, had the least biomass, whilst the biomass of the sides was at an intermediate level. Maximum basal biomass was in excess of 70gAFDWm⁻², whilst the maximum biomass of the top faces only reached about 20gAFDWm⁻².

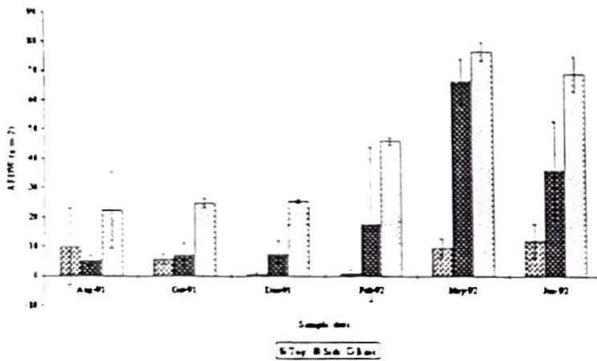


Fig. 5. Total epibiotic biomass (g AFDW m⁻²) from the tops, bases and vertical sides of the fly ash slabs from August 1991 until June 1992

Biomass of mobile epifauna:

The small mobile organisms, such as small crabs and polychaetes contributed about 1-12% of the total biomass component (gAFDW) of each block sampled. The contribution tended to be greater in the late winter when large molluscs such as *Buccinum undatum* and *Ocenebra erinacea* were found breeding on the reef and the amount of epifauna present on the blocks was low prior to the main season of recruitment.

The contribution that was made to the biomass of the slab epibiota by the small mobile epifauna, for example the polynoids and the crab, *Pisidia longicornis*, was only 0.01-7% of the total biomass (gAFDW) of each slab sampled.

Biomass determinations of other sites:

The biomass of the epibiota on the tops and bases of the Tal-y-foel tiles, sampled on 12 August 1991, was 58.16 and 106.59 gAFDWm⁻² respectively. The major contributors to the biomass were *Balanus crenatus* and ascidians.

The biomass of the Middle Poole Patch epibiota determined

from the 28 August 1991 sample, was 17.20gAFDWm⁻².

Discussion

There was a tendency for the epibiotic biomass to be greater on the concrete blocks, with exceptions occurring only when there was a high proportion of eggs present in the fly ash samples compared to that found in the concrete ones. This was a result of the high organic content and thus high AFDW of the eggs, as compared to those for the encrusting organisms, for example. During the early part of the year the concrete sample biomass tended to be in excess of four times greater than that for the fly ash, whilst the biomass was similar to that found on the fly ash in July and then one and a half to two times greater again during the summer and autumn.

Samples from early 1991 and 1992 were affected by the necessity to rebuild the reefs following the passage of an oyster dredge through the reef site the previous winter. These events caused the most damage to the fly ash reef and resulted in the death of some of the organisms, either by reorientation of the blocks or smothering in seabed sediment.

The biomass of the epibiota from the concrete reef in May 1992 was much higher than in previous samples. This can be explained in part by a larger than usual amount of erect species and sponges. Trends in biomass with respect to block type were not observed for the taxa, eggs and ascidians.

The encrusting organisms were observed to have formed a background community on the artificial reef (Fig. 4). The biomass proportion of these organisms declined over the summer months as the percentage contribution to the biomass made by taxa such as the erect organisms (Fig. 4) and eggs (Fig. 4) increased. This can be explained in terms of a greater diversity of organisms being present during the summer and thus demonstrates the effects of seasonality in the PBAR epibiotic community.

The larger biomass of the August 1990 and June 1991, fly ash samples (Fig. 4), resulted from the presence of large specimens of the solitary ascidian (*Ascidia mentula*) which helped to produce an ascidian biomass for these samples of up to four times greater than those for the other blocks sampled at these times. In addition the ascidian biomass for the August 1990 fly ash sample was twice as much as that found on the concrete block, which was a consequence of a 'bloom' of the colonial ascidian *Aplidium* sp. On the former substrate, whilst any other anomalies between the ascidian biomass for the concrete and fly ash samples resulted from the combined effect of both solitary and colonial ascidians.

As a result of sampling lower reef blocks, the majority of which exhibited a negligible basal biomass, it is likely that the estimates of whole reef biomass will be minimum values. However, it was likely that external reef block faces experienced a greater biomass of epibiota than the faces nearer to the centre of a reef unit as a result of less recruitment in the latter region and therefore the biomass values obtained for the blocks that were sampled, probably supported a representative biomass of epibiota when viewed in the context of a whole reef

unit. Where tops and bases were equally available for colonisation, biomass was similar.

The amount, and the orientation of the space available for colonisation on the PBAR slabs was more consistent than found on the sampled blocks, particularly as all of the slab bases were available. The slabs exhibited the lowest biomass (gAFDWm^{-2}) of epibiota on their upper surfaces with time (Fig. 5), as a result of siltation on these faces, which may have prevented recruitment.

In general, the same species contributed to the biomass of both the vertical sides and the bases of the slabs. Lower biomass per unit area however was recorded on the vertical sides than on the bases. This may be explained by rust from the frame rails staining the sides of some of the slabs and thus providing an unfavourable surface for settlement of epifauna, together with recruitment and growth being restricted to the spaces between the sides of the slabs and the rails. In addition, the bases had a greater number of both encrusting organisms and ascidians recruiting to them than did the sides. These animals, for example *B. crenatus*, *Ascidia* sp. and *Aplidium* sp. are negatively phototactic and thus prefer settlement sites with low light levels [11] [12] [13]. Organisms living on the slab bases also experienced an unrestricted current flow which may have provided them with a good supply of growth promoting food. Scouring by suspended sediment in the water column did not appear to affect basal colonisation. The basal biomass increased with time, representing an increase in recruitment together with the growth of species that were already present.

The biomass of the PBAR slabs was found to be relatively low when compared to other studies (Table 1). This may be explained in terms of length of submergence and depth together with other physical and biological constraints. A greater biomass per unit area was however generated on the slabs than on the reef blocks, resulting from the undersides of the slabs having been available for colonisation, whereas in general block bases were not.

The biomass of the epibiota on the slabs was comparable to that found at Fawley, Hampshire, UK [14] (Table 1), whilst the block biomass was similar to that found on Middle Poole Patch (Table 1). This illustrated that the reef was capable of sustaining a biomass of epibiota equivalent to that found on the slightly sloping surfaces of a local, mature, natural reef which supported similar species to PBAR, whilst if more block undersurfaces were free for colonisation the potential biomass would have been even greater. Samples were taken from the sides of the rocks of Middle Poole Patch as there were relatively few flat horizontal faces, and those that were available were covered in silt.

The Tal-y-foel tiles had large mussels and oysters growing on them which were major contributors to the sample biomass (Table 1). In addition the epifaunal community on these tiles had had longer to develop and grow than that found on the PBAR blocks or slabs. The much higher biomass recorded for the Langstone Harbour study [5] (Table 1) can be attributed to the presence both of the bryozoan *Alcyonidium gelatinosum* and also of larger solitary ascidians than found on PBAR.

Epibiotic biomass values reported from a storm surge barrier, about 8-10y after its emplacement in the Oosterschelde estuary

LOCATION	DEPTH	TIME	AFDW (gm^{-2})	REF.
Middle Poole Patch	12 m	> 10 y	17 (AF)	[1]
PBAR blocks (May 1991)*	12 m	2 y	18 (AF)	[1]
PBAR slabs - Tops	12 m	1 y	0-25 (AF)	[1]
- Vertical sides			2-72 (AF)	
- Bases			15-94 (AF)	
Tal-y-foel tiles	ELWS	2.25 y	88 (AF)	[1]
Fawley	< 5 m	1.25 y	48 (EAF)	[14]
Langstone Harbour 1	> 4 m	1 y	370-495 (AF)	[5]
Langstone Harbour 2	> 4 m	2 y	125-278 (AF)	[5]
Oosterschelde estuary	<15 m	10 y	186-468 (AF)	[4]
North Sea wrecks	15-35 m	> 10 y	1179 (AF)	[3]
Black Sea - oil rig	22 m	1.5 y	72 (EAF)	[6]
Black Sea - seawalls	< 5 m	5 y	266 (EAF)	[6]
Daya Bay, China	< 5 m	1 y	91 (EAF)	[10]
SCG artificial reefs - Tops	22-31 m	3.5-10 y	22-49 (EAF)	[7]
- Sides			44-80 (EAF)	
SC panels - Tops	20 m	1 y	7-53 (EAF)	[9]
- Vertical sides			11-61 (EAF)	
- Bases			21-57 (EAF)	
Delaware artificial reef	9-13 m	2 y	6-249 (EAF)	[8]

Table 1 A comparison of ash-free dry weight (AFDW) data for PBAR slabs and blocks with other sampling sites: time refers to the length of submergence of the structure; * are maximum study values; AF is the AFDW; EAF is the estimated AFDW using conversion factors from [1] as AFDW was not determined in these studies; Langstone Harbour 1 & 2 represent a community before and after the decline of ascidians respectively; SC and G denote South Carolina and Georgia; and REF relates to the reference of the study.

[4] (Table 1) were comparable with values from Tufnol panels in Langstone Harbour [5], but higher than any recorded in the present study. The relatively high biomass of the epifaunal communities found on established shipwrecks in the North Sea [3] (Table 1) can be attributed to the abundance of large specimens of the anemone *Metridium senile*, which has a relatively high amount of fatty tissue. In both the Dutch studies, the epifaunal communities were well developed and had a large proportion of sponges and other late colonists which contributed to about one third of the total biomass.

Whilst it is unknown whether the WW reported by other authors [6] [7] [8] [9] [10] have been accurately converted to AFDW in Table 1, it is likely that the resulting AFDW represent at least minimum values for the respective epibiotic communities. In general, the artificial structures that have been in place for only a short time period had estimated biomass values similar to those found in the present study.

The PBAR slabs and blocks exhibited a similar epibiotic biomass to the Delaware reef [8], once the mussel, *Mytilus edulis* had declined in the Delaware community (Table 1). The maximum biomass for the vertical sides and bases of the PBAR slabs was comparable to that found on the Tal-y-foel tiles and on the vertical sides of the SCG reefs [7] (Table 1). The biomass from the Tal-y-foel tiles was comparable to those reported for both the Black Sea oil rig [6] and the Daya Bay panels [10] (Table 1).

The range of estimated epibiotic biomass from the horizontal faces of the SCG reefs [7] and the SC panels [9] fitted in between the values from the top surfaces of the PBAR blocks and the Tal-y-foel tiles, whilst the biomass from the tops of the

PBAR slabs tended to be lower than those observed in the aforementioned studies. The epibiotic biomass of the PBAR slabs was similar to that of the SC panels, where the differences in maximum horizontal surface biomass may be explainable in terms of depth, current speed and amount of siltation at the respective sites. The estimated biomass for the vertical surfaces of the SCG reefs [7] (Table 1) compared well with those on the vertical sides of the PBAR slabs and the SC panels [9], towards the end of their respective sampling programmes, when maximum biomass values were realised. This last comparison reflects the difference that submergence time can make to the epibiotic biomass as the SCG reefs had been in place for 3.5-10y, whereas the PBAR slabs and the SC panels were each submerged for a year in total.

The seawall community of [6] consisted mainly of the mussel, *Mytilus galloprovincialis*, which is a very different community to that found on PBAR and is thus not strictly comparable.

The contribution made to the biomass by small mobile invertebrates was generally negligible, but tended to be at a maximum in the late winter. This was because molluscs such as *Buccinum undatum* and *Ocenebra erinacea* were found breeding on the reef at this time. These organisms had high AFDW's compared to the low biomass contribution from the relatively small amount of epifauna present on the blocks, prior to the main season of recruitment.

A number of problems arose in determining biomass data. Many of the organisms started to decay on removal from the blocks and it was therefore necessary to prepare them for the oven as quickly as possible. The taxa groups chosen had to be broad, owing to time constraints that would have been required for the separation of all of the organisms even into Phyla. [7] experienced problems in the separation of bryozoans from hydroids and of tube worms from their host organisms.

The present study was the first of its kind to quantify the biomass in terms of AFDW of the sessile and small mobile epibiota of an artificial reef and thus there was little or no previous research to compare accurately with it, as assumptions must be made to convert WW to AFDW and these can lead to incorrect estimations, depending on the conversion factors for the species involved. It can be concluded however, that PBAR has supported a sessile community of epibiota that has a comparable biomass to that found on a local, mature, natural reef and that if more of the undersides of the blocks were available for colonisation, then the potential biomass would be much greater, particularly over the course of time once certain taxa have had an opportunity for growth. Finally, whilst the total epibiotic biomass was generally found to have been greater on the concrete blocks, the percentage contribution of the major taxa to the biomass was unaffected by block type.

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